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PROCEEDINGS OF A WORKSHOP TO IDENTIFY HIGH PRIORITY PROBLEMS OF ANIMAL NUTRITION THAT SHOULD BE ADDRESSED BY THE AGRICULTURAL RESEARCH SERVICE

HELD AT BELTSVILLE, MARYLAND
APRIL 5-6, 1988

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EXECUTIVE SUMMARY

The participants at the workshop identified five high priority general problems that were judged appropriate for extensive research efforts by ARS scientists during the next five-ten years. These general problems were:

1. Inadequate understanding of normal physiological process, mechanisms of growth promoting action and regulation of feed intake restricts improvement of animal production efficiency and reduces quality of animal products.

2. Lack of nondestructive techniques to assess dynamic changes in body composition of animals restricts our ability to design production systems that efficiently produce animal products of optimal composition.

3. Animal performance is often restricted by inadequate information on the chemical composition of feedstuffs and the presence of anti-quality factors or natural toxicants which reduce feed intake or act as antimetabolites for productive processes.

4. Little information is available on the energy costs of digestion and the relationship of these costs to feed quality or physiological state.

5. Interrelationships between genotype, management, nutrient intake and disease needs to be identified and quantitated in modern production systems in order to provide a rational basis for development of ways to prevent production losses.

Each of these five general problems had four to six subproblems identified. Following the workshop, the six most important subproblems were prioritized.

These subproblems, in order of priority, are as follows:

1. Lack of detailed knowledge of factors which affect metabolism of target tissues (such as regulators of gene expression of the endocrine system or control of protein synthesis during production of meat, milk, eggs and wool).

2. Lack of information of nutrient absorption and metabolic costs associated with absorption and lack of understanding of factors that regulate the absorptive process and recycling of nutrients restricts efforts to improve feed efficiency and production.

3. Lack of validated and standardized direct and indirect nondestructive techniques for determining body composition (nuclear magnetic imaging resonance, computer assisted tomography, high frequency ultrasound, near infrared reflectance, etc. may be the standard technique with which to validate other techniques in the future).

4. Inability to define and measure the chemical and physical characteristics of complex carbohydrate and lignocellulose complexes in plant cell walls restricts our ability to predict and improve nutrient availability for productive function.

5. Inadequate understanding of the factors affecting fermentation in the rumen and lower gut hampers the ability to determine the relative importance of fore and hind gut contribution to utilization of feed components, particularly structural carbohydrates at high levels of intake.

6. Lack of knowledge regarding the effects of genotype, management system and nutrient intake on immune system function and disease processes restrict our ability to prevent production losses.

Two special research activities were identified during the workshop as deserving special emphasis in ARS nutrition research programs. Since these were activities rather than problems, they were weaved into the appropriate subproblems. One of these activities was developing techniques and capabilities, such as NMR imaging/spectroscopy techniques, to monitor body composition of live animals during various phases of the production cycle. Without this nondestructive capability it was concluded progress would be greatly restricted. The other activity was use of systems research to integrate nutrition research and integrate nutrition research within the overall production systems. This was important in order to be able to effectively deliver and supply research results at the producer level. A large percentage of ruminants go through a range/pasture animal production system. Numerous animal and plant factors interact in these systems that are not understood. Information gaps in the system format are captured in the problem statements listed in this summary.

PROGRAM AGENDA

AGRICULTURAL RESEARCH SERVICE ANIMAL NUTRITION WORKSHOP
April 5-6, 1988
Conference Room 4
Building 005, BARC-West
Beltsville, MD

OBJECTIVE: Identify and prioritize the goals of the ARS Nutrition Program to improve animal nutrition, productivity, and product quality. Special emphasis will be placed on evaluation of ways to increase the protein yield of animals.

April 5, 1988

8:00 - 8:10am	Welcome and opening remarks about goals of the Workshop. (Travis Littledike, NPS, Beltsville, MD)
8:10 - 8:25am	Overview of ARS Production Research. (Roger Gerrits, NPS, Beltsville, MD)
8:25 - 9:00am	Overview of present ARS Nutrition Program. (Travis Littledike, NPS, Beltsville, MD)
9:00 - 9:40am	Economic and consumption trends--considerations that impact animal production now and in the future. (Kenneth Nelson, Robert Bishop, William Hahn, ERS, Washington, DC)
9:40 - 10:00am	Break

Problem 1: Difficulty in accurately producing slaughter animals with predetermined body composition.

10:00 - 10:30am	An Overview: Gaps in our current state of knowledge that prevent us from accurately controlling body composition and especially the protein yield of animals by nutritional means. (Wilson Pond, USMARC, Clay Center, NE)
10:30 - 11:00am	Possible approaches to elimination of the gaps that prevent us from accurately controlling body composition of animals and especially production of protein and fat. (Henry Tyrrell, BARC, Beltsville, MD)
11:00 - 11:30am	Genetic and physiologic approaches to reducing fat in poultry. (Lee Cartwright, Georgetown, DE)

Problem 2: Difficulty in controlling the partitioning of nutrients during various stages of production.

11:30 – Noon	Use of chemicals and hormones as partitioning agents to increase protein yield of animals. (Norman Steele, BARC, Beltsville, MD)
Noon – 1:00pm	Lunch

Problem 3: No practical method to determine or predict exact body composition during various stages of animal production.

1:00 – 1:30pm	Possible approaches for estimation of body composition of animals during various phases of the production cycle and at slaughter. (Andrew Hammond, Brooksville, FL)
1:30 – 2:00pm	Application of NMR technology to determine body composition. (Alva Mitchell, BARC, Beltsville, MD)
2:00 – 2:30pm	Effect of body composition on palatability and consumer acceptance of animal products. (Calvin Farrell, MARC, Clay Center, NE)

Problem 4: Need to reduce the fat content and alter the composition of fat in animal products.

2:30 – 3:00pm	Controlling fat synthesis and degradation (Dennis R. Campion, Athens, GA)
3:00 – 3:15pm	Break
3:15 – 4:30pm	The two subgroups meet to develop prioritized lists, narrative statements, and lists of major thrust areas for ARS Nutrition Program for next 5-10 years. Group A will work on ruminants--beef, dairy, and sheep. Group B will work on nonruminants--swine and poultry. Separate lists for each species will be needed.
4:30 – 5:00pm	Spokesperson from each of the two subgroups presents prioritized lists and comments to entire group for comment.

April 6, 1988

8:00 - 8:30am	Ruminant (Room 135) and nonruminant (Room 227) groups meet separately to develop final lists and narrative statements as necessary.
8:30 - 9:00am	Meeting of entire group (Room 227)--a spokesperson from the ruminant (Rumsey) and nonruminant (Steele) groups present their final lists and narratives to entire group for discussion.
9:00 - 10:00am	Ruminant (Conference Room 4) and nonruminant (Room 227) groups meet separately to suggest possible cooperative research efforts (where, when, how, and who) on prioritized items.
10:00 - 10:15am	Break
10:15 - 10:45am	Ruminant and nonruminant groups each present their suggestions to the overall group (Conference Room 4) for additional ideas and suggestions.
10:45 - 11:30am	Ruminant (Conference Room 4) and nonruminant (Room 227) groups each meet separately to modify and finalize their plans.
11:30 - Noon	Ruminant and nonruminant groups present their final plans to the entire group in Conference Room 4.
Noon - 1:00pm	Lunch and end of meeting.
Followup	Chairmen and NPS person will develop the final proceedings booklet for the workshop over the following few weeks and distribute it to all appropriate persons. Summarized presentations from participants made on Monday and Tuesday will be published in the proceedings of the Workshop.

FINAL RECOMMENDATIONS OF NUTRITION WORKSHOP

The problems and subproblems (prioritized under each problem) identified at the workshop were as follows:

General Problem 1:

Inadequate understanding of normal physiological process, mechanisms of growth promoting action and regulation of feed intake restricts improvement of animal production efficiency and reduces quality of animal products.

a. Lack of detailed knowledge of factors which affect metabolism of target tissues (such as regulators of gene expression of the endocrine systems or control of protein synthesis during production of meat, milk, eggs and wool).

b. Need to improve techniques available to quantify body protein degradation in large food producing animals.

c. Lack of knowledge of the effect of maternal nutrient status on fetal/embryonic development pattern and early growth on the subsequent performance of offspring.

d. Inadequate understanding of feed intake regulation as a means to accelerate rate of product formation and control composition of product.

e. Integrate and expand knowledge of metabolic modeling to those factors associated with livestock production.

Narrative:

Considerable knowledge exists regarding the biochemical events associated with protein synthesis; however, virtually no knowledge or valid technique exists to quantify protein degradation.

General Problem 2:

Lack of nondestructive techniques to assess dynamic changes in body composition of animals restricts our ability to design production systems that efficiently produce animal products of optimal composition.

a. Lack of validated and standardized direct and indirect nondestructive techniques for determining body composition (nuclear magnetic imaging resonance, computer assisted tomography, high frequency ultrasound, near infrared reflectance, etc. may be the standard technique with which to validate other techniques in the future).

b. Methods are needed to quantitate in situ metabolism of targeted tissues (i.e., it may be feasible to use NMR spectroscopy to determine iron status, ATP/ADP ratio, stable isotope abundance of specific tissues, etc.).

c. Lack of methods to serially monitor the effects of maternal nutrient status and metabolic regulators on the growth and development of the fetus/embryo.

Narrative:

Current comparative and slaughter balance methods require a single end point measurement of composition changes which possibly occurred early in the course of experimental treatment. Current methods for measuring fractional rates of synthetic and degradative processes associated with tissue growth are either indirect, subject to large sampling error or destructive. These factors have prevented extensive experimentation of many aspects of animal production, especially growth and development and development processes and progress in genetic selection.

General Problem 3:

Animal performance is often restricted by inadequate information on the chemical composition of feedstuffs and the presence of anti-quality factors or natural toxicants which reduce feed intake or act as antimetabolites for productive processes.

a. Inability to define and measure the chemical and physical characteristics of complex carbohydrate and lignocellulose complexes in plant cell walls restricts our ability to predict and improve nutrient availability for productive function.

b. Incomplete understanding of animal and diet factors that influence appetite and feed intake of animals precludes determination of intakes optimized for productivity.

c. Lack of knowledge on the relationship between level and kind of supplementation and the basal range, pasture or forage diet restrict the optimum utilization of range, pasture and forage feed resources.

d. Inadequate understanding of animal and plant factors that influence diet selection by animals.

e. Integrate and expand nutrient database information into production system models.

Narrative:

Current analytical methods need to be refined and new methods developed to identify the complex chemical and physical characteristics of plants that restrict or enhance utilization of plant nutrients.

General Problem 4:

Little information is available on the energy costs of digestion and the relationship of these costs to feed quality or physiological state.

a. Lack of information of nutrient absorption and metabolic costs associated with absorption and lack of understanding of factors that regulate the absorptive process and recycling of nutrients restricts efforts to improve feed efficiency and production.

b. Inadequate understanding of factors that influence rate of digestion and passage hampers the ability to improve the utilization of feed components. Development of intrinsically labelled feedstuffs would expedite progress.

c. Inadequate understanding of the factors affecting fermentation in the rumen and lower gut hampers the ability to determine the relative importance of fore and hind gut contribution to utilization of feed components, particularly structural carbohydrates at high levels of intake.

d. Lack of information about optimal ratios of ingredients in mixed diets, which, when consumed in large amounts and digested incompletely prevents improvement in efficiency of conversion to useful products.

e. Integrate expanding knowledge of gastrointestinal tract function into working systems models of digestion/absorption related to animal performance.

Narrative:

Prior to the assimilation of feed nutrients for maintenance or component tissue growth, dietary nutrients consumed by ruminant animals are subjected to microbial transformations, degradations and factors in the gastrointestinal tract. Information is needed about the feed nutrients themselves and the processes that affect them prior to assimilation and utilization if optimization of feed utilization is to be accomplished.

General Problem 5:

Interrelationships between genotype, management, nutrient intake and disease needs to be identified and quantitated in modern production systems in order to provide a rational basis for development of ways to prevent production losses.

a. Lack of knowledge regarding the effects of genotype, management system and nutrient intake on immune system function and disease processes restrict our ability to prevent production losses.

b. Lack of knowledge of optimal nutrient requirements of diseased animals restricts the ability to minimize production losses.

c. Lack of knowledge of nutrition necessary to optimize disease prevention through such measures as induction of active and passive immunity.

d. Lack of accurate quantitation of the production costs of disease restricts the ability to choose the most economical ways to prevent disease and reduce losses.

APPENDIX

I. Written Presentations Given at Workshop

II. Written Research Goals Submitted Prior to Workshop by the Various Locations

III. ARS Nutrition Program Categorized by Subject

IV. Classification of ARS Nutrition Program by Steps in Utilization of Nutrients

I. WRITTEN PRESENTATIONS GIVEN AT WORKSHOP

- Nutrition Research in ARS - Dr. E. T. Littledike - Beltsville.
- Knowledge gaps that hinder control of body composition and protein yield of animals by nutritional strategies - Dr. W. G. Pond - MARC.
- Elimination of gaps which prevent accurate control of the composition of animal products, especially production of protein and fat - Dr. N. F. Tyrrell - Beltsville.
- Genetic and physiologic approaches to reduce fat in poultry - Dr. Lee Cartwright - Georgetown.
- Possible approaches for estimation of body composition of animals during various phases of the production cycle and at slaughter - Dr. A. C. Hammond - Brooksville.
- Application of NMR technology to determine body composition - Dr. A. D. Mitchell - Beltsville.
- Effect of body composition on palatability and consumer acceptance of animal products - Dr. C. L. Ferrell - MARC.
- Controlling fat synthesis and degradation - Dr. D. R. Campion - Athens.
- Monoclonal antibodies against procine adipocytes - Dr. J. T. Wright - Athens.

The goal of ARS is to provide the means to solve the high national priority technologic food and agricultural problems through fundamental and applied research. The overall aim is to ensure the continuation of an adequate supply of food and fiber of high quality to meet the needs of the American people and for export.

ARS has 8,120 employees, with 2,642 scientists at 127 locations. Our budget in 1987 was about $512 million and has remained essentially constant, when adjusted for inflation, since 1981. As of 1985, animal productivity research (objective 3) accounted for 19 percent of our budget. In 1987, animal productivity (objective 3) accounted for about 17 percent of our budget. This decreased percentage results from congressional add-ons not directed to animal productivity.

ARS had about $75 million (net to location) or $94 million appropriated in 1987 in animal productivity, which amounted to $196,000/CRIS (net to location). ARS has 421 scientists located at 28 domestic locations and 3 foreign locations in objective 3. ARS has 147 scientists working with beef, 109 in dairy, 66 in poultry, 70 in swine, 33 in sheep, and 5 with other animals. ARS spends $28 million on beef, $23 million on dairy, $14.5 million on poultry, $19.75 million on swine, $7.5 million on sheep, and $2 million on other species.

As stated in the 6-Year Agricultural Research Service Program Plan for 1986-1992 under objective 3, ARS develops the means to increase productivity (interpreted now as increase production efficiency) and the quality of animal products. Net to location dollars to do this are $76.5 million/year.

ARS has six approaches to do this.

1. Genetic - which has $6 million, --- SY, and 39 projects with appropriated funds.

2. Reproduction - which has $7.2 million, --- SY, and 42 projects.

3. Nutrition - which has $12.6 million, --- SY, and 70 projects.

4. Diagnostics - which has $37.5 million, --- SY, and 16 projects.

5. Parasite Control - which has $10.6 million, --- SY, and 53 projects.

6. Integrating Systems - which has $2.9 million, --- SY, and 17 projects.

We are all aware that agriculture continues to evolve and change. There are the cyclical economic changes in each commodity group that are inherent in a supply/demand driven industry as it adjusts to the various

economic factors that influence it. There are fundamental changes that reflect, in part, U.S. agriculture's adjustment to changes in the global agriculture industry. World competition has caused us to look into our production systems for new ways to increase our world competitiveness.

This has put great pressure on the groups that provide the research and development for U.S. agriculture to find ways to increase or maintain our relative ability to compete in world commodity markets. There is also pressure on ARS and all of agriculture to effectively address food safety and quality, environment, and animal welfare issues. Changes in farm policy impact on how the agriculture industry changes and what type of research and development may be needed to allow agriculture to change in response to these policy changes.

For example, we have heard recently that the administration is willing to do away with subsidizing of agriculture trade commodities to promote free trade. How might this be related to ARS research if such a change occurred? First, let's look at what has happened in the dairy industry. In 1955, we had 2.8 million dairy farms with an average of eight cows each. In 1985, we had only 274,000 dairy farms, and, of these, we had only 175,000 commercial dairy farms (defined as farms with more than five dairy cattle). The average dairy farm has about 65 cows.

Thus, in the last 30 years, we have had a 90 percent reduction in the number of dairy farms, and an 8-fold increase in number of cows per farm. The average cow produced 5,842 lb/year in 1955 and 13,000 lb/year in 1985, a 2.25-fold increase in milk produced/cow. Obviously, the window that constitutes good or adequate management is now much narrower with these high producing cows, and the research that is needed to supply the producer with the information needed to profitably produce milk from these cows is much different than for the old low producing cow.

We essentially have no world market for our dairy products at present, as only 2 percent of our dairy products move abroad. This is because most countries heavily subsidize their dairy industry, and thus the products are only domestically consumed or each country's dairymen produce products in great excess for government purchase and storage. There is little supply and demand relationship in production because the government buys the overproduction of manufacturing grade milk (that used to manufacture dairy products). This support price affects the price of fluid grade milk (the milk we drink at the table) because the manufacturing grade milk is the basis for determining the price of the higher valued fluid grade milk.

Another example of change is the pig industry. Pig farms have increased in size (96 to 145 hogs/farm since 1980) because, within limits, the higher the hog production from a given size facility, the lower will be the fixed cost of ownership. Bulk purchase discounts of feedstuffs, supplies, etc., gives advantage on the input side to the large farms and in general there is improved efficiency in use of feed, labor, breeding stock, and capital resources. Specialized confinement swine housing, better techniques for record keeping, crossbreeding, ration balancing,

health programs for the breeding herd, etc., can be economically justified on the larger units. These same factors promote contract feeding of hogs and a cookbook style of management once a workable system has been proven.

The research needed to supply the needed technology for managing large hog units and herds of pigs is different in many respects than that needed for small units that may manage pigs as individuals rather than as a large herd.

Concern about high-fat products has caused an extensive reappraisal of many agricultural products.

It is currently possible to produce a product that seems to meet the low-fat market demands by trimming various amounts of the external fat from products that originally contained excessive fat. Conditions in the current market system make it more economical to produce the excessively fat product because the majority of feed for these animals is produced by a heavily government-subsidized grain production system. The current large decrease in the demand for our grain in the world market puts additional pressure on producers to increase the value of their grain by feeding it to animals, and since most aspects of the market currently reward producers for producing fat, they have little or no economic alternative to the current system.

With the current variability in the production system, the amount of marbling in meat cannot accurately be controlled. Since the grading system is geared heavily to marbling characteristics, a large number of our cattle are seed to ensure that sufficient numbers are available in the choice grade. The cattle that fail to meet these higher grades are used to satisfy the low-fat meat demand since they have to be marketed. The current system leaves little room in the marketplace for a consistently high-quality, low-fat, very palatable product to be superimposed on the current supply of low-fat meat, especially since a very palatable low-fat meat needs to be sold at a premium price because it is more expensive to produce this type of meat. Current grading systems and pricing systems would discriminate against such a product. The difficulty of marketing such a product is increased because techniques are not currently available to easily identify and grade the palatability of such a product to insure consistent quality.

The cattle industry is, however, getting pressure from the medical community to reduce the fat content of their product to aid consumers in adjusting their overall diets to include no more than 30 percent fat and to reduce cholesterol consumption. The cholesterol consumption of about 25 percent of the consumers is considered to be too high and to present a health risk and contribute to heart disease, the number one U.S. health problem. Commodities that are viewed by the consumer as more healthful and less expensive are enjoying large per capita consumption increases while consumption of cattle meat products are steadily decreasing. These changes may be magnified in the future by increases in the percentage of

older people in the population that will eat less meat and in general consume much less food because of lower requirements of food for activity and growth.

The cattle producers would appear to need several pieces of information before they can commit their resources to production of a given product mix.

1. What is the market presently and potentially for the various types of cattle meat products?

2. Will the portion of the marketing system between the producer and the consumer reward the producer for producing cattle tailored to produce each of these products?

3. If the producer decides to produce such a product, will the necessary information, seedstock, feeding systems, and grading and marketing systems be available to maximize the producer's competitiveness in the system? Can the producer tailor the production system to maximize the producer's advantage to produce a given product for the market or should he produce a general product that can be produced by most of the animal production systems and that can be used in many ways, even though the industry seems to be losing its competitive advantages in the marketplace? In brief, should the producer go for short-term or long-term goals?

4. Will the consumer's taste continue to change in the future as it has in the past? How much should the industry change to meet the current perceived needs of the consumer? Should they only respond to the packers' (short-term) needs and rely on that to ensure the future health of the industry?

I have summarized or categorized the ARS nutrition program in two different ways in the appendix of the proceedings of the workshop. The first classification (Appendix I) indicates that the nutrition program as it now exists emphasizes forage utilization, animal growth, nutrient digestion, absorption and metabolism, and hormonal regulation of metabolism. Appendix II gives a more detailed breakdown of the ARS nutrition program classified by steps in the utilization of nutrients. Most of the research program when viewed in this way can be generally categorized under digestion and metabolism. Research on the various aspects of metabolism is the major emphasis at present.

KNOWLEDGE GAPS THAT HINDER CONTROL OF BODY COMPOSITION AND PROTEIN YIELD OF ANIMALS BY NUTRITIONAL STRATEGIES

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Gaps in our knowledge of control of body composition of food animals by nutritional strategies have been identified and discussed at several symposia and workshops in the past few years (Animal Agriculture: Research to Meet Human Needs in the 21st Century, Westview Press, Boulder, CO, 1980; Diamond Jubilee Issue of J. Anim. Sci. 57(Suppl. 2):1-575, 1983; Proc. Anim. Sci. Workshop, USDA-ARS-Cornell Univ., Beltsville, MD, 1985; Current Concepts of Animal Growth, J. Anim. Sci. 61(Suppl. 2):1-184, 1985; Current Concepts of Animal Growth, J. Anim. Sci. 63(Suppl. 2):1-114, 1986; Designing Foods: Animal Product Options in the Market Place, Natl. Acad. Sci., Washington, DC, 1988). Major knowledge gaps that invoke constraints on control of body composition and protein yield of animals by nutrition include:

Cellular control of protein and lipid synthesis and degradation. A more complete understanding of these mechanisms will allow exploration of ways by which nutritional, endocrine and other physiological parameters can be manipulated to affect body composition (lean tissue output).

Nutrition x genetic interactions in protein and lipid accretion in growing animals. The lean tissue and depot fat accretion curves of animals of different genotypes during growth are clearly different, but there is a serious void in understanding of the role of feed intake level and feed composition on the body composition response of animals of divergent genetic backgrounds. A more complete understanding of how diet variables, i.e., nutrient density, level of intake, interact with animal genotype to affect the protein and fat accretion curves in ruminants and nonruminants is needed to develop feeding strategies which will maximize protein yield and efficiency of feed resource utilization.

Diet composition and level of feed intake: effects on visceral organ size and whole body energy expenditures. Recent revelations of the impact of visceral organ size on whole body basal energy requirements dictate that accelerated research effort be directed toward quantifying these relationships. The effect of diet composition and level of intake on visceral organ mass, metabolic rate and its contribution to total energy expenditures during growth, reproduction and lactation needs quantification in ruminants and nonruminants.

Intestinal tract microbiology and animal protein yield. Although a large body of knowledge has accumulated on the microbial populations and anaerobic fermentation processes in the rumen, gaps still exist in manipulation of rumen microflora to maximize lignocellulose utilization and to take full advantage of the rumen "by pass" concept associated with differences in dietary protein solubility for maximization of dietary nitrogen utilization for highest protein (lean meat) yield. Limited information is available on the extent of lignocellulose degradation by anaerobic lumen microflora in the lower intestinal tract of ruminants and nonruminants on the absorption of volatile fatty acids produced by microbial fermentation of feed residues. The feasibility of utilizing recombinant DNA techniques to increase cellulolytic capability of

microbial inhabitants of the GI-tract is unknown. The role of the microflora of the GI-tract in the mechanisms of action of antibiotics and other antimicrobial agents in improving growth rate in animals is still not completely understood. A more complete understanding of microbe x host interactions in relation to adaptation of animals to changes in diet composition is needed. All of the above constraints are researchable and successful solutions will result in opportunities for increased animal productivity and protein yield.

Maternal nutrition during gestation: effects on progeny development. Evidence exists that maternal gestation diet of nonruminants has important effects on progeny postnatal development, but the extent and nature of these effects are not well understood. There is a serious lack of knowledge of the overall impact of gestation feeding schedules of nonruminants and ruminants on overall animal production efficiency and on protein yield. Life cycle feeding and management research is expensive and slow, yet needed answers to these questions will be available only by such effort.

Effect of exogenous protein anabolic agents on nutrient requirements. The documented enhancement of lean accretion and reduction in fat content of carcasses from animals administered exogenous nutrient repartitioning agents (somatotropin, beta-adrenergic agonists, ionophores) produces unknown effects on dietary requirements for specific nutrients. Research aimed at quantifying the changes in specific nutrient requirements induced by these agents is needed to allow maximum exploitation of their beneficial effects on protein yield. There is no information available on genetic x exogenous agent interactions in the response of ruminants or nonruminants and no knowledge of three-way interactions (genetic x endogenous agent x nutrition) which may be operative in affecting the response.

Nutrition x disease interactions. There is a dearth of information available on the interrelationship between nutrition and infectious disease in food animals. Nutritional deficiencies or imbalances may influence the immune system of animals or may affect the course of an infection by facilitating invasion by secondary infective agents, or by delaying recovery from the disease. The importance of nutrient concentrations in the diet in preventing or controlling infectious diseases (bacterial, viral, parasitic) is largely unknown and untested. While protein yield per animal may not be directly affected by the presence of infectious diseases in animals not overtly affected, the potential importance of interrelationships between nutrition and disease in ruminant and nonruminant animals in relation to overall animal productivity is largely uncharted.

A word on animal models. Selection of appropriate animal models to study animal nutrition in relation to productivity, protein yield and product quality is clearly important to enhance the odds of accumulating knowledge for broad application across the animal industry (i.e., large and small frame cattle; lean and obese pigs).

ELIMINATION OF GAPS WHICH PREVENT ACCURATE CONTROL OF THE COMPOSITION OF ANIMAL PRODUCTS, ESPECIALLY PRODUCTION PROTEIN AND FAT.

Henry F. Tyrrell

Domestic animals used for the production of agricultural products have evolved over many generations. The physiological and metabolic controls which permit farm animals to grow and produce are complex, deeply interrelated, and resistant to dramatic shifts in response to the changing needs of man. Dramatic increases in animal productivity have been accomplished through improved nutrition, management, and genetic selection. But, I would suggest that changes in metabolic pathways, control mechanisms, and basic physiology have been relatively minor. For example, the amount of milk produced by the average dairy cow in the United States has more than doubled in my lifetime, but how has that increase been accomplished? First, cows of higher genetic potential for milk production are available as a result of intensive genetic selection using the principles of additive genetic variation combined with the technology of artificial insemination. Second, more specific knowledge is available concerning nutritional requirements and other factors necessary to formulate rations which can be consumed in the quantity required to meet the nutrient requirement of the high producing cow. Third, knowledge of disease control and treatment has improved so that animal health can be maintained at a level which minimizes negative effects on productivity. Finally, management skills have improved so that dairymen are aware of and have available to them the tools necessary to care for high producing cows in a manner which permits the cow to more fully express her genetic potential for milk production. I would suggest that what has been changed by genetic selection is the number of secretory cells which develop in the mammary gland and the development of other organs necessary to 'feed' the secretory tissue. I am not aware of data which would support the arguement that a secretory cell in the low producing cow functions differently from a secretory cell in the high producing cow. On a more practical level, the higher production efficiency of the modern dairy cow is fundamentally the result of dilution of the maintenance overhead and not the result improved efficiency of conversion of nutrients by the mammary gland per se.

I would raise a similar question with respect to the growing animal as well. To what extent can improved animal performance be attributed to enhanced function at the cellular level vs greater proliferation of one type of cell over another? Much of the emphasis toward larger frame size in cattle and the production of lean beef is the result of slaughter of larger maturing cattle at similar body size and thus a younger physiological maturity than smaller breeds. The down side of this process is a greater maintenance overhead cost to the total beef herd as well as a higher maintenance cost for the slaughter animal itself. There is another relationship in growth which appears quite difficult to change. When we partition total tissue energy retention (Mcal/d) between energy in protein vs energy in fat, we routinely find more than 75% in fat and less than 25% in protein. In females, this ratio approaches 90:10. Unfortunately, I have not looked at data from intact males. Another component of this partition relationship is that at zero tissue energy retention, ie., maintenance, energy is being retained in tissue protein and energy is being lost from tissue fat. Another use of this partition relationship demonstrates that under conditions of insufficient dietary protein, tissue energy is retained in the form of fat rather than protein. Unfortunately, excessive dietary protein does not increase partition of tissue energy towards tissue protein. This in essence is the bottom line to nutritional control of the composition of animal products. A nutritionally imbalanced diet has two detrimental effects on animal production. Most often intake will be reduced depressing the rate of energy yield in animal product, or if intake is not limited, partition of energy yield in animal product is towards fat and away from protein.

GENETIC AND PHYSIOLOGIC APPROACHES TO REDUCE FAT IN POULTRY

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This presentation summarizes research conducted to describe development of adipose tissue in rapidly growing broiler chickens. I hope this information changes the way some researchers think about fat development in the growing animal.

We have had difficulty controlling fat deposition. We are frustrated with the recalcitrance of adipose tissue which will not conform to our will. However, I am beginning to look at this problem a little differently. I propose that adipose tissue will respond in any way that we wish. The problem is that we are not willing to accept the responses of other tissues to our treatments that reduce fat deposition.

Over the last several decades hypotheses have been promulgated about how adipose tissue develops in young animals. This information is based upon research conducted with animal models of an inappropriate age or stage of development. Most of these animals have been adult rats and mice when the studies were performed. Changes in body composition are much easier to effect without appreciably damaging lean growth in an animal which is past the rapid growth phase. These results have misrepresented the difficulties faced when one trys to devise a method to improve body composition in the very young, rapidly growing animal.

The modern broiler chicken is a fast-growing, efficient animal. The chicken is marketed as a lean meat source. The fat of the broiler chicken is largely confined to the intermuscular fat. Abdominal fat is 15-20% of total carcass fat, is easily removed, and is generally discarded. Cutaneous fat makes up a considerable proportion of the remaining fat. The chicken and the turkey have the unusually lean muscles of the breast which comprise a considerable proportion of the carcass. These are the sources of advantage of poultry over other meat animals to claim the "lean" label. However, todays broiler stocks are 150 to 200% as fat as broiler stocks that were used in the 1950's.

Adipose tissue cellularity was measured in growing broilers which either were allowed to consume feed on an ad libitum basis or were overfed to induce excessive development of adipose tissue. While adipose tissue development and body fat composition was exaggerated in the overfed broilers permanent changes were not observed either in adipose cellularity or in

body composition. When lipectomy (partial removal of abdominal adipose tissue) or sham operations were performed on ad libitum and overfed animals no affect on cell size was detected. No compensatory increase in abdominal adipocyte cell number was observed even though the number of measurable adipocytes was rapidly increasing during the study.

Voluntary feed intake was reduced to 80% of ad libitum levels after overfeeding was stoped. This reduction of feed intake continued until body composition and mean adipocyte volume were approximately the same as the voluntary feed intake levels of control broilers. This reduction of feed intake appeared to occur even at the expense of lean growth.

Adipose tissue cellularity was affected by feed restriction at maintenance levels early in the life of the chick. Cell number was affected at the expense of body size. Less severe feed resriction delayed growth of young broilers and compensatory growth ensued with an apparent decrease in percentage of body fat. These results might be explained by permanent stunting of body size and slower compensatory growth of adipose tissue deposition.

A body of information is currently accumulating which describes biochemical and physiological patterns consistent with fatness or leanness in animals. This information should lead us to conclude that the characteristics consistent with a desirable body composition requires more than a change in diet. Some of the physiological characteristics associated with large lean body mass are also associated with excessive development of body fat. Fat development in the growing animal might necessarily be a consequence of rapid growth and large body size.

Current broiler diets are formulated with very low levels of fat and with appropriate nutrient formulations to minimize fat deposition in broilers. Barring any unforeseen breakthrough, manipulations of the diet or feeding regime will not elicit the kind of changes in body composition required by the poultry industry. As nutritionists we need to look at nutrition at a cellular level, to determine how nutrition affects the environment of a tissue type or cell type. We are well equipped to determine what biochemistry or physiology needs to be affected, how to affect these critical sites, and finally to determine what these changes require nutritionally. Dietary induced changes in physiology and biochemistry can give us a great deal of information necessary to identify candidate functions for manipulation which will ultimately result in improved body composition.

POSSIBLE APPROACHES FOR ESTIMATION OF BODY COMPOSITION OF ANIMALS DURING VARIOUS PHASES OF THE PRODUCTION CYCLE AND AT SLAUGHTER

Andrew C. Hammond

Interest in body composition and the composition of growth in food producing animals has existed for more than a half-century. Currently, measurement of body composition is particularly of interest in studies of growth, nutrient use, nutrient partitioning, the dynamics of body stores and realimentation, genetic selection and product quality. Table 1 is a selected list of methods that have been used or proposed for use in the study of body composition. Some of these are used routinely in certain situations and will be discussed with regard to advantages and limitations. Emphasis will be given to application to nutritional studies in beef cattle.

General Considerations

The first consideration in selecting an approach to the study of body composition revolves around objectives of the study. A study of nutritional effects on fat depots would likely require physical dissection and(or) direct chemical analysis while a study of nutritional effects on energy deposition over time may involve a dilution approach or physiological measurements of gaseous exchange. A study of the effects of nutrition on compositional endpoints related to salable product would take yet a different approach. It would probably be appropriate to point out here that body composition may be taken to mean chemical composition of the total body, empty body or carcass, or the mass of various separable tissues and organs. Another general consideration would be the research environment. Research capabilities with respect to instrumentation and facilities vary widely, and commercial application outside of a controlled research environment imposes other considerations. And it probably goes without saying that any method or approach would ideally be nondestructive, rapid, simple, accurate, precise, inexpensive and provide a minimum of disruption to the animal or body fraction being studied.

Specific Considerations

Chemical analysis

Direct chemical analysis is perceived to be the most accurate and precise method for the determination of empty body or carcass composition. Limitations include expense involved, equipment required for grinding whole carcass and noncarcass fractions, loss of water by evaporation during the slaughter and grinding process, and the limitation to single endpoint or serial slaughter approaches.

Empty body weight and carcass weight

Empty body weight can be determined at slaughter by the difference between total live weight at slaughter and the contents of the gastrointestinal tract and bladders or it can be predicted from carcass weight (Lofgreen et al., 1962; Garrett and Hinman, 1969; Fox et al., 1976). Use of empty body weight removes the variation due to gut fill and there are general relationships between empty body weight and body composition or carcass weight and carcass composition (Meissner et al., 1980ab; Hammond et al., 1984; Hammond et al., 1988). These relationships tend to have fairly high standard errors of the estimate and these approaches are also limited to single endpoint or serial slaughter.

Physical separation and chemical analysis of indicator cuts

Use of the separable components of the 9-10-11th rib or the chemical composition of the soft tissue of the 9-10-11th rib to predict carcass composition was proposed by Hopper (1944) and Hankins and Howe (1946) and is still widely used. This is a fairly simple approach and can be used when direct chemical analysis of the whole carcass or determination of carcass specific gravity is not possible. Expense is minimized in that only a small percentage of the salable carcass is used. A major limitation appears to be that the prediction equations proposed by Hankins and Howe (1946) are not entirely appropriate for all types of cattle (Field, 1971; Crouse and Dikeman, 1974).

Other indicator cut approaches are also used and include wholesale cuts, retail cuts and other specific anatomically defined fractions.

Carcass specific gravity

Carcass specific gravity is widely used to predict carcass and empty body composition and was the method used in serial slaughter experiments on which the California net energy system is based (Lofgreen and Garrett, 1968). This method often has been used to determine body composition with which estimates based on other indirect methods are compared. One limitation to this approach is that the predictive ability of carcass specific gravity for estimating carcass or empty body composition is low for lean or young cattle, i.e., those less than about 200 kg or less than about 15 or 20% body fat.

Live weight

Live weight is easily determined and is generally related to body composition. Any other method that does not have the ability to predict body composition more precisely or more accurately than live weight is of little practical use. Live weight has the advantage of being able to make repeated measurements over time on the same animal but suffers from the variation due to gut fill. Variation due to gut fill can be minimized by taking repeated measurements over two or three consecutive days or by removal of feed and(or) water for a set period of time (e.g., overnight) prior to weighing to obtain a shrunk weight.

Dilution

Dilution approaches are based on the observation that the proportion of chemical components in the fat-free body mass tends to be relatively constant (Pace and Rathbun, 1945; Reid et al., 1955) so that determination of one component allows estimation of the other components. Water is the largest component in the fat-free body and has served as the basis for dilution approaches in cattle. Among several compounds that have been used, tritiated water often has been chosen because other than small isotope effects it behaved as water and was easily measured. Limitations to the use of tritiated water are difficulty in disposing of the radioactive material and loss of salable product due to radioactivity. Deuterium oxide is often currently used but analysis is somewhat cumbersome and requires special analytical instrumentation. Deuterium oxide is particularly suited to studies of water kinetics and a two-pool approach has been proposed by Byers (1969) which provides an estimate of water in the gastrointestinal tract and therefore an estimate of gut fill along with the estimation of empty body composition. The validity and usefulness of the two-pool approach for the prediction of gut fill

has been challenged by other workers (Trenkle, 1986), but deuterium oxide should be as good as any other marker using a one-compartment model. Urea dilution is used by some workers because it is relatively inexpensive and requires relatively simple analytical techniques. Most often, a single postinfusion blood sample is used to estimate urea space which is then related to body water and other body components (Preston and Kock, 1973; Kock and Preston, 1979; Hammond et al., 1984; Hammond et al., 1988). All of the water dilution approaches suffer the same limitations as carcass specific gravity in terms of age and leanness of the animal, i.e., low predictive ability for relatively young or lean animals, but dilution approaches have the advantage of being able to make multiple measurements over time on the same animal.

Two recognized limitations of the water dilution approach are the variability in live weight due to gut fill (previously discussed) and real departures from the observation that composition of the fat-free body is constant (due to differences associated with age, sex and physiological state). In practice, gut fill can be determined at slaughter and used within dietary treatments to estimate previous gut fill. Alternatively, empty body weight can be estimated from carcass weight and gut fill determined by difference between live weight and empty body weight. These two approaches to estimation of gut fill do not account for the reduced percentage of gut fill related to increased live weight. The Agricultural Research Council (ARC, 1980) has derived formulas for the estimation of gut fill which takes this into account and relates gut fill to physical composition of the diet, i.e., dry roughages vs. concentrates, etc. With regard to differences in the relationship among fat-free empty body components, different prediction equations may be required for widely varying types of cattle.

<u>Ultrasound</u>

Common ultrasonic techniques used involve either a point estimate of fat depth or a cross-sectional image from which fat thickness and sometimes rib eye area can be estimated. Intuitively and usually in practice the fixed-image cross-sectional method is less variable and more accurate but the instrumentation involved is more expensive. One application of this approach is estimation of slaughter endpoint, and is often compared to subjective condition score for this purpose.

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TABLE 1. SELECTED APPROACHES

<u>Direct Methods at Slaughter</u>

- Chemical analysis

<u>Indirect Methods at Slaughter</u>

- Empty body weight
- Carcass weight
- Physical separation of carcass or indicator cuts
  - 9-10-11 Rib
  - Others
- Chemical analysis of carcass or indicator cuts
  - 9-10-11 Rib
  - Others
- Carcass specific gravity

<u>Indirect Methods in Live Animals</u>

- Live weight
- Linear measurements and body surface measurements
- Fat probe
- Dilution
  - Tritiated water
  - D_2O
  - Urea
  - Antipyrene
  - Others
- Instrumental
  - Ultrasound
  - ^{40}K
  - Conductance
  - X-ray, CAT scan
  - NMR
  - Others
- Physiological measurements
  - Oxygen consumption
  - Creatinine excretion

<u>Subjective Methods</u>

- Condition score
- Frame size
- Muscle score
- Marbling score

ARS Animal Nutrition Workshop
April 5-6, 1988
Beltsville, MD

APPLICATION OF NMR TECHNOLOGY TO DETERMINE BODY COMPOSITION

by

A.D. Mitchell

Nuclear magnetic resonance or NMR spectroscopy has been a powerful tool of the analytical chemist for several years. More recently, advances in NMR spectroscopy and the development of imaging techniques have resulted in the ability to probe the intact organism in a manner which was previously attainable only by invasive procedures or by the use of ionizing radiation. This technology is proving to be a valuable medical diagnostic procedure. Because of its capability for imaging fat, muscle and other internal organs in the live animal and for the spectoral determination of lipid and water content we have sought to apply this technique to the study of body composition.

The NMR procedure requires that the animal be immobilized during either imaging or spectroscopy. With instruments currently available, whole body spectroscopy capability appears to be limited to small animals (i.e., chickens or smaller), however, for imaging purposes, whole body imagers are available with a 1 M diameter chamber, which could handle a market weight pig. For body composition studies NMR imaging can provide both quantitative and structural information. The NMR image depends on differences in water proton content and NMR relaxation times of various tissues. Cross-sectional images obtained from pigs and chickens have revealed with excellent contrast the location of fat, muscle and internal organs.

Quantitative information can be obtained by tracing the area of interest from the image or by allowing the computer to select the total area based on a specified image intensity or pixal density. This information could be gathered from a series of images throughout the body. Another approach which is now possible is through a computer generated graphics technique called volume visualization. This technique displays a volume of data rather than its surfaces or edges. This would allow the reconstruction of a muscle, organ or fat depot. Total imaging time will depend on the number of image slices needed and, therefore, the size of the animal and may range form several minutes to an hour or more. A sequence of a dozen slices would require approximately 20 minutes.

Differences in the NMR behavior (chemical shift) of water and lipid protons result in signals which can be resolved in a frequency spectrum. ^{1}H-NMR spectroscopy of a series of 20 and 50 g samples of pork tissues (composite of fat and muscle) have produced excellent correlation between NMR signal height or area and tissue content of lipid, water or protein. Similar results have been obtained using whole body spectroscopy for a group of control and obese mice. Whole body ^{1}H spectra have also been obtained from chicken and turkeys ranging up to 1000 g. However, the larger the animal the more difficult the procedure and more time is required to shim the instrument in order to improve the homogeneity of the magnetic field. A potential mode of spectroscopy for application to the larger animal is that of localized spectroscopy, i.e., composition of a specified area.

This is a rapidly growing technology with potential applications to animal science far beyond that of compositional analysis. Furthermore, advances in magnet construction resulting in more powerful and homogeneous magnetic fields and the rapid proliferation computer techniques will likely overcome some of the problems which are now encountered.

EFFECT OF BODY COMPOSITION ON PALATABILITY AND CONSUMER ACCEPTANCE OF ANIMAL PRODUCTS---A SYNOPSIS

C. L. FERRELL

In general, three major factors are involved in consumers' selection of animal products: cost, convenience and palatability. The relative importance of these factors varies with several things, such as economic status, number of persons in the household who work outside the home, age, area of the country, etc. Leanness and palatability are primary considerations in the selection among and/or within red meat sources. Lean meat is generally preferred. The American public has become more health conscious than in the past and animal fat (whether because of fat per se or because fat contributes to increased energy in the diet) is perceived as having an adverse affect on health. The trend in recent years has been toward decreased consumption of animal fat by selection of leaner products and by trimming excess fat. The primary consideration of the presentation is the extent to which palatability (flavor, juiciness and tenderness) may be altered by attempts to meet consumers demand for lean meat.

Carcass composition of sheep or cattle may be altered by sex condition, breed substitution, exogenous hormones or other growth stimulators, or feeding regimen. Some of the largest differences have been observed in response to altered sex condition. A review of several studies indicated, for example, bulls gained 21% more rapidly, had 13% greater feed efficiency and yielded 5% more retail product than steers. At similar weight or age, bulls contain less fat and more lean or protein than steers. Similar effects have been observed in rams versus wethers. In laboratory tests, flavor, juiciness and tenderness have been very acceptable for both males and castrates, but steers have been consistently, slightly more tender. Similar trends, but of smaller magnitude, have been reported when cattle of breeds having large mature size are compared to those of smaller mature size and when exogenous growth promotants have been given. Animals fed to gain at higher rates contain a higher proportion fat and a lower proportion lean or protein. Differences achieved by economically feasible feeding regimens are relatively small however. As with other factors that result in altered body composition, the influence of altered feeding regimen on sensory characteristics evaluated in the laboratory have been small.

CONTROLLING FAT SYNTHESIS AND DEGRADATION

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While the title of this presentation in its strictest sense may conjure up images of biochemical pathways, shunts, cycles, etc., the topic has been addressed in a slightly different manner. Regardless of approach, what is of interest is a reduction in the amount of carcass fat of our meat animals. Furthermore, this reduction must be accompanied by some gain in efficiency. This subject could easily fill textbooks, and, in fact, it does. But, for the purpose of discussion (and because of my biases), three points will be addressed which offer potential (but not exclusive) means to achieve the overall goal of fat reduction. While not covered in any detail herein, the fact that growth hormone and the ß-agonists retard net lipid deposition in fat cells is well established.

I. Endocrinology

The precise elucidation of hormonal control of preadipocyte growth and differentiation will increase the potential to develop a physiological

approach to manipulation of fat deposition in meat animals. A large body of literature describing endocrine regulation of lipogenesis and lipolysis exists. Primary culture of stromal-vascular (SV) cells has now progressed to the point that cultures can be grown in defined (serum-free) medium. Recently, Hausman (1988) reported success using this approach to culture pig SV cells. This development will be of particular use to evaluate cellular regulatory mechanisms in response to specific factors.

The fetal hypophysectomized pig offers an excellent model to determine the regulation of fat cell number as the hypophysectomized pig has about half the number of lipid-filled cells as control fetuses at 110d of gestation. An endocrine component appears to be involved as fetal hypox serum caused a reduced rate of preadipocyte growth when compared to control pig serum. (Jewell and Hausman, Unpublished).

II. Growth factors and gene regulation.

One of the major challenges in eukaryotic molecular biology is to elucidate the mechanisms governing transcriptional regulation. Another challenge is to determine how these mechanisms are integrated into an orderly pattern of cell growth and tissue development. Little work has been done in this area with respect to the fat cell. Adipsin (Flier et al., 1987) and G6PDH, LPL and IGF-I (Doylio et al., 1987) mRNA probes, have been used to study the effect of various agents/conditions on gene expression in adipocytes. Spiegelman and co-worker (Rauscher et al., 1988) have identified the location of an

upstream promoter element, FSE2 for the aP2 gene. When a protein complex containing Fos protein is present, transcription is inhibited. But if the Jun (AP-1) protein is present the promoter is activated. Growth hormone regulates the abundance of IGF-I mRNA. This regulation of IGF-I gene expression is rapid, reversible and takes place primarily at the transcriptional level (Doglio et al., 1987). Others showed that IGF-I stimulated c-fos gene expression (Ong et al., 1987) and clonal expansion of 3T3-L1 preadipocyte (Zezulak and Green, 1986). Whether c-fos expression in response to IGF-I is related to the mitogenic action of IGF-I is not known.

III. Growth Inhibition

A. Cell surface antigens

In 1985, researchers at the Hannah Research Institute, Scotland, reported that passive immunization of rats with an antiserum to the fat cell resulted in long-term reduction of adiposity (Futter et al., 1985).

Wright et al. (1987, 1988 a,b) is studying adipogenesis through detection of adipocyte surface antigens by monoclonal antibodies. As Dr. Wright has developed a summary on this research for this Workshop, I will limit comment other than to indicate that monoclonal antibodies are powerful tools 1) to study adipogenic lineage, 2) to make uniform preparation of cells and 3) to target specific cells *in vivo*. Thus, this approach is relevant to the study of each of the three points made in this presentation.

B. Growth inhibitors

Others (Sparks and Scott, 1986; Ignotz and Massaqué, 1985) showed that transforming growth factor-ß (TGF-ß) inhibited differentiation when added to cultures of preadipogenic cell lines. We have confirmed this effect using SV cells of pig subcutaneous adipose tissue in micromass culture. As TGF-ß has been postulated to have a role in fetal development, we have examined developing subcutaneous adipose tissue of the pig from 35d to 110d of gestation for TGF-ß using immunocytochemical and colloidal gold procedures. (Campion and Richardson, 1988; Richardson and Campion, 1988). No staining was revealed in the subcutaneous layer at 35 d. By 50 d TGF-ß positive cells were associated with forming capillary networks. Between 70 d and 110 d positively stained adipocytes were usually clustered around blood vessels that also contained numerous TGF-ß positive platelets. Electron microscopic evaluation revealed TGF-ß labeling within the thin area of adipocyte cytoplasm but no labeling on the outer membrane of developing adipocytes. These results indicate that TGF-ß may be involved in regulation of angiogenic activity, and possibly in formation or regulation of adipocyte development in subcutaneous adipose tissue of fetal pigs. While TGF-ß is present in adipocytes and cells associated with developing capillary networks, the physiological role of TGF-ß during early adipose tissue development is not known.

Generally inhibitors of somatomedin-like activity are sensitive to nutritional status. There are a number of studies to demonstrate that

the inhibitory activity of serum from fasted animals is greater than that from fed animals. The interaction between nutrition and specific inhibitors per se is not known at this time.

Also, the nutritional requirements of an animal with an experimentally reduced number of fat cells will have to be established as this type of model becomes available.

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MONOCLONAL ANTIBODIES AGAINST PORCINE ADIPOCYTES

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These experiments describe the first monoclonal antibodies (MAbs, designated AD-1 and AD-2) against porcine adipocytes. Surface immunofluorescence analysis revealed expression of the AD-1 and AD-2 antigens by mature adipocytes in stromal-vascular cell cultures, and by adipocytes and associated capillary networks *in vivo*. Immunoprecipitation of iodinated adipocyte plasma membrane proteins followed by SDS-polyacrylamide gel electrophoresis and autoradiography yieled specific protein antigens for each antibody. Increased expression of both antigens concomitant with fat cell cluster formation was demonstrated using an indirect antibody binding assay. The AD-1 and AD-2 antigens were also detected on a subpopulation of cells in cultures prior to adipocyte differentiation, indicating that cells along the adipogenic lineage possess distinct cell surface markers which are present prior to overt adipocyte differentiation *in vitro*.

The AD-1 and AD-2 MAbs were used to examine adipocyte differentiation *in vivo*. Whereas cytodifferentiated adipocytes are first detectable in fetal adipose tissues around 60 days of gestation, the AD-1 and AD-2

antibodies each detected cells in the innermost layer of dorsal subcutaneous tissue at 35 days of gestation. By 50 days of gestation, AD-1-positive cells were present throughout the innermost and middle subcutaneous tissues, while AD-2 reactivity was not as extensive in the middle subcutaneous region. By 60 days of gestation, both antibodies detected lipid-filled cells and associated capillaries in the innermost and middle subcutaneous layers, as well as between underlying muscle fiber bundles. Between 60 and 110 days of gestation, the pattern of reactivity observed with both antibodies correlated with the appearance of fat cell clusters. Results thus far indicate that expression of both the AD-1 and AD-2 antigens precedes adipogenesis in the fetal pig.

Research in progress is taking four approaches: (1) depletion of antigen-positive cells (preadipocytes) from adipose tissue cell suspensions. Cells bearing determinants for the AD-1 and AD-2 MAbs are selectively removed from cell suspensions by treatment with antibody-coated magnetic microcarriers. Removal of cells expressing the AD-1 antigen results in reduced fat cell cluster formation in cultures, (2) optimization of adipocyte differentiation in vitro. Immunofluorescence analysis revealed a slower replication rate for the antigen-positive (preadipocyte) cell subpopulation in cultures. Seeding cultures at higher densities than normally used resulted in increased fat cell cluster formation, (3) in vivo targeting of adipocytes with MAbs. The AD-1 and AD-2 antibodies were administered intravenously to newborn pigs. Examination of tissues by immunofluorescense revealed specific targeting of both antibodies to adipocytes, whereas no antibody reactivity was observed in non-adipogenic tissues, (4) preparation of additional

anti-adipocyte MAbs. Plasma membranes are currently being isolated from both adipocyte and preadipocyte cell subpopulations.

Once characterized, the complete panel of adipogenic lineage-specific MAbs will be used as cytotoxic agents and as carrier molecules for targeting cytotoxic agents to adipose tissues for reducing adipose tissue mass. In addition, the ability to extract homogenous populations of cells will allow more critical study of the actions and interactions of various growth factors and inhibitors on the proliferation/differentiation of preadipocytes.

II. WRITTEN RESEARCH GOALS SUBMITTED PRIOR TO WORKSHOP BY THE VARIOUS LOCATIONS

MARC	Key research goals for improved nutrition, productivity and product quality of food animals.
BELTSVILLE	Nonruminant Animal Nutrition Laboratory; Livestock and Poultry Sciences Institute.
BROOKSVILLE	Key research goals.
EL RENO	Prioritized research goals.
MADISON	Major problem areas in animal nutrition for the U.S. Dairy Forage Research Center
BELTSVILLE	List of Research Areas for Nutrition Workshop
DUBOIS	Improving Efficiency of Protein Production in Lambs

KEY RESEARCH GOALS FOR IMPROVED NUTRITION, PRODUCTIVITY AND PRODUCT QUALITY OF FOOD ANIMALS

USDA, ARS, ROMAN. L. HRUSKA U.S. MEAT ANIMAL RESEARCH CENTER

Objective: Improve animal nutrition, productivity and product quality with special emphasis on increasing protein yield of animals.

Knowledge gaps:

Constraints on progress in animal nutrition, productivity and product quality (principally increased lean to fat ratio) have been identified and discussed previously (Animal Agriculture: Research to Meet Human Needs in the 21st Century, Westview Press, Boulder, CO, 1980; Proc. Symposium on Food Animal Research, Lexington, KY, November 1986; Diamond Jubilee Issue of J. Anim. Sci. 57(Suppl. 2):1-575, 1983; Current Concepts of Animal Growth, J. Anim. Sci. 61(Suppl. 2):1-184, 1985; Current Concepts of Animal Growth, J. Anim. Sci. 63(Suppl. 2):1-114, 1986; Proc. Animal Science Workshop, USDA-ARS and Cornell University, April 1985; NRC. Designing Foods: Animal Product Options in the Market Place, Natl. Acad. Sci., Washington, DC, 1988). Major knowledge gaps which appear to impose constraints on progress include the following:

Cellular controls of protein and lipid anabolism and catabolism. Fundamental controls of protein synthesis and degradation and of lipid synthesis and degradation in animal cells are not fully understood. An understanding of these rate-determining steps and their mechanisms will allow manipulation and enhanced efficiency of animal protein production by nutritional, endocrinological and other physiological means.

Genetic x nutrition interactions in protein and energy accretion. The lean tissue and fat depot accretion curves of animals of different genetic backgrounds during growth are clearly different and there is a serious void in knowledge of the physiological controls that effect differences among genotypes in altering utilization of nutrients and body composition in response to changes in dietary intake and composition. In addition, more work is needed on interactions between genotype and nutrient requirements for maintenance, gestation, and lactation.

Effect of diet intake and composition on visceral organ size. Recent revelations of the impact of visceral organ size on whole animal basal energy requirement dictate that accelerated research effort be directed toward quantifying the importance of diet intake and composition in affecting visceral organ mass and metabolic rate in all food animal species and in animals of different genotypes.

Role of microbe: host relationships in the gastrointestinal tract. Serious gaps still exist in knowledge of microfloral-host interactions in the rumen and lower intestinal tract with respect to adaptations of the microbes and host to diet composition; microbial attachment to feed residues and to intestinal mucosa; cellulolytic capacity of microfloral populations; and the total impact of gut microflora on animal productivity. A void in the knowledge of GI tract microbial adaptations of importance in substrate metabolism in ruminants and nonruminants in association with the response of visceral organs to changes in diet intake and composition precludes accurate prediction of overall animal productivity.

Maternal nutrition during gestation: effects on progeny development. Available evidence suggests important effects of maternal gestation diet

on progeny postnatal development, but there is a serious lack of knowledge of such effects on overall animal production efficiency and on protein yield. Life cycle feeding and management research in ruminant and nonruminant animals is needed to identify and quantify these effects.

Physiological bases for the nutrient repartitioning effects of exogenous protein anabolic agents. The observed enhancement of lean accretion and reduction in fat content of carcasses from animals administered exogenous agents (somatotropin, beta-adrenergic agonists, ionophores) need to be characterized and quantified further. Regional changes in blood flow in response to beta-adrenergic agonists have an unknown cause:effect relationship to the observed repartitioning effect. A more complete knowledge of the mechanism of action of the improved lean tissue accretion will provide insight into the fundamental controls of protein and lipid metabolism referred to earlier. Alterations in body composition resulting from use of repartitioning agents may have important effects on nutrient requirements and life cycle feeding and management systems. Any increase in quantitative dietary requirement for protein or other nutrients induced by administration of anabolic agents will need to be considered in developing strategies of use for maximum economic gain.

Genetic, nutritional, and sex condition on meat quality. Genetic variation and production practices affect meat quality--especially tenderness. Also, biological changes that occur within the muscle tissue during animal growth and development that causes the variability in tenderness are poorly correlated with fat deposition. The mechanisms by which genetic, nutrition, and sex conditions affect meat quality are not known, but must be resolved before known technologies that will improve

production efficiency and product leanness can be implemented, because these same technologies are often antagonistic to meat tenderness.

Non-invasive methods for estimating body composition in live animals. Despite intensive efforts by many biologists extending over many years, there is still not an accurate method available for determining protein, fat, water, and ash in living animals. The limitations of deuterium oxide, 40 K counting, total-body electrical conductivity (TOBEC), and other non-invasive methods are documented. Inability to determine accurately and economically the body composition of live animals at a given body weight remains as a major deterrent to monitoring tissue growth and product value before slaughter in ruminants and nonruminants. This deterrent must be addressed by emphasis on new methods with potential in animal production.

Feeding strategies allowing limited feeding of individual animals penned in groups. The well known effect of restricted feed intake on body fat accretion is not efficiently applied in group housing situations due to social dominance and feeder space limitations. If commercialization of "pin pointer" and similar electronic devices for individual rationing of predetermined feed allowances could be made cost effective, excess carcass fat could be avoided while improving efficiency of feed utilization. Such a system would also allow tailored feeding of animals in a group differing in genetic background, sex condition, or nutritional requirements to maximize efficiency of feed resource utilization.

Modeling animal production systems. Animal modeling techniques have been applied at the cellular, organ, or whole animal level, and attempts are underway to develop total enterprise model systems for cattle, sheep, and swine with aggregation of lower level details. A major constraint to the

development of enterprise models is the sparsity of information to:

1. describe mechanistic details of nutrition and related physiology in a quantitative form, and
2. quantify interactions between nutrition and other aspects of integrated production systems.

Further advances in knowledge of cellular control of nutrient utilization and of nutritional mechanisms of interactions accrued through experimentation will provide the basis for more relevant modeling of entire production systems.

United States Department of Agriculture
Agricultural Research Service
Beltsville Area Beltsville Agricultural Research Center
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March 23, 1988

Nonruminant Animal Nutrition Laboratory; Livestock and Poultry Sciences Institute

Growth as defined from a generalist's viewpoint is the hypertrophy of differentiated tissues as directed by the genetic agenda and constrained within current knowledge by environmental factors, including nutrient environment. Current livestock production practices stress the utilization of those gene pools, or agendas, which favor the accretion of lean muscle tissue and modest amounts of body fat. With recent recommendations by the biomedical community to reduce lipid intake, particularly those of a saturated nature of animal origin, to 30% of total caloric intake (currently 38%), increased pressure on the livestock production sector to decrease fat content of animal products can be anticipated. Concurrently, agricultural research has the obligation to producers to increase production efficiency and profitability. The following list of queries is provided by the Nonruminant Animal Nutrition Laboratory staff regarding growth and development processes which may impact on the rate and efficiency of lean tissue deposition.

General: Focus, through the CRIS project system, animal production research to maximize protein yield per animal unit. This requires concurrence in research direction by the NPS and others and requires that this singular goal of research represent Agency policy. The majority of current projects would fit into this objective, but some less focused efforts may require redirection. Several strengths of ARS are the competence of researchers and stability of funding both of which would be required for substantive progress. This point was not unanimous among staff.

Problem #2: Control nutrient partitioning during various stages of production.

1. Trace mineral metabolism: basic research on the transfer of trace minerals from maternal stores to the fetus/embryo. Research would involve the isolation and characterization of metalloproteins as these proteins effect transfer, uptake, distribution and storage of trace minerals. Possible examples include iron "loading" of the developing pig fetus rather than iron supplementation postpartum and regulation of avian trace mineral transfer to the developing egg and the role of metals in embryonic viability.

Effect of stress and disease on trace mineral partitioning. Due to the utilization of trace minerals in those processes related to immune system

function and stress adaptation, appropriate nutritional management may reduce the impact on productivity of such conditions.

2. Immunomodulation of growth: techniques for autoimmunization against such factors as somatostatin, lipid synthesizing enzymes, adipocyte membrane proteins (receptors) have sporadically excited the scientific community; however, indepth consideration of these techniques (i.e., repeatability, success of immunity induction, species-specificity, impact on growth) has not been attempted.

3. Mode of hormone action: evidence is accumulating that the B-agonists are not pure catecholamines in function, but may act as trophic factors stimulating mitogen production and this possibility warrants further investigation. Perhaps a commonality to growth promoters (B-agonists and somatotropin) resides at a fundamental level of cell physiology common to all tissues (nerve-derived mitogens?).

4. (General) Develop scientific capabilities in bone physiology: with the current tools available to alter dietary nutrient partitioning into body compartments the next likely limiting factor for realization of genetic potential could be frame-size. With few exceptions ARS lacks researchers trained in bone physiology (cell culture, cartilage metabolism, mineralization). This expertise would be of considerable value as related to growth and development studies.

5. Protein degradation: livestock agriculture invests considerable resources to the evaluation of protein deposition, but no method exists for the quantitative determination of protein degradation rate. Exploratory research into methods development appears warranted considering the impact of protein degradation processes as related to growth promotants and lean tissue accretion.

Problem #3: Practical methods to predict body composition at various stages of animal production

1. Evaluate the potential for NMR imaging and spectroscopy in the nondestructive analysis of animal growth components (quantity and distribution of fat, muscle size, visceral organ mass and possibly the degree of lipid unsaturation). NMR technology could be appropriate for real-time *in vivo* measurements of energy metabolism.

2. Role of nutrient management techniques (i.e., use of energy dense high-lipid diets) to overcome the maturity problem with respect to meat tenderness in "growth enhanced" animals.

Problem #4: Need to reduce fat content and alter the composition of fat in animal products

1. Despite the problems with fat deposition, especially saturated fatty acids, in livestock species, aquaculture benefits from the relationship

between omega-3 fatty acid intake and HDL levels in humans. Examine the regulatory role of copper in the fatty acid desaturase enzyme system of aquatic species and the dietary control of this enzyme activity.

United States Department of Agriculture
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March 17, 1988

SUBJECT: Key Research Goals

TO: E. Travis Littledike
National Program Leader
Animal Nutrition

FROM: Andrew C. Hammond
Research Leader

Dr. Mimi Williams from our Station at Brooksville suggests that the following research goal be included in our discussions.

> Increase the efficiency and lean product quality of forage-based beef cattle systems (particularly in the subtropical U.S.) by development of grazing systems with improved seasonal distribution of dry matter and improved forage quality.

The production of beef slaughter animals exclusively on a forage diet can result in more desirable lean to fat ratio (albeit, often at the expense of flavor and tenderness). While cattle produced in the subtropical regions of the US are shipped to other areas of the country for a combination of backgrounding and/or feedlot, forage finished beef remains the only practical system for the beef production in most tropical and subtropical regions of the world. Forage quality and/or quantity problems during various times of the year in these regions, often result in cattle requiring 3 - 4 yrs to reach market weight on all forage diets, which impart accounts for the lower carcass quality. The development of grazing systems that result in improved dry matter distribution and forage quality could significantly shorten the time require to grow and finish slaughter animals and improve the market quality of the lean beef produced. Such systems, by minimizing the need for concentrate inputs, could also result in the practical finishing of slaughter animals the subtropical regions of the US.

PRIORITIZED RESEARCH GOALS
SUBMITTED BY
USDA, ARS, FORAGE AND LIVESTOCK RESEARCH LABORATORY
EL RENO, OKLAHOMA 73036

1. Ability to predict chemical composition of wholesale cuts from live animal measurements in a rapid and routine manner.

2. Understand the biology of growth and development and its influence on the composition of the carcass so that composition can be predicted or a nutritional regimen defined to achieve a desired composition. This includes the interrelationships between nutrient load, age of the animal and endocrine function, whether endogenous or exogenous, and their affect on the partitioning of nutrients among various body tissues.

3. Determine the appropriate levels of fat in meat products to insure a nutritious, tasty product and define factors which modify the influence of fat levels on the palatability of meat.

RATIONALE AND JUSTIFICATION

A. Conference problem 3.

As the emphasis for leaner meat in the marketplace increases, there may also be a need for a labeling scheme that insures a cut of meat has a certain composition of fat and protein. This emphasis will lead to a need to monitor the composition of various muscles and their covering in the live animal so that the feeder and packer both know the precise time to slaughter an animal to meet the needs of the consumer. To monitor animals in such a way will require a rapid, semi-portable technique that is suitable for automation and that can be used either by feedlots or buying consultants. Current non-destructive methods include various dilution methods for measuring total body water which is then used to estimate the fat percentage of the empty body or carcass. This method is too slow to be used in a commercial environment. Near-infrared spectroscopy used in the transflectance mode has been used to estimate body composition in humans. It is currently being tested in pigs. However, differences in the layering of fat, skin thickness and hair covering may provide difficulties, for using NIR to estimate fat composition in ruminants. The difficulty of confirming its usefulness is the lack of good reference methods. Presently whole body dissection with measurement of chemical composition is the most reliable but it is costly and laborious. Further, there is a need to know the contributions of the various wholesale cuts of the carcass to the whole carcass composition. Coordination is needed among labs researching different techniques so that the same cattle may be used by all groups, thus reducing the confounding of data sets with the technique.

B. Conference problem 2.

Although considerable research is directed towards repartitioning nutrients during the finishing phase of growth, it is important to note that 80% of the total nutrient intake of ruminants comes from forage based system. Whether this growth is supported indirectly in the form of maternal nutrition during the prenatal and preweaning stages of growth or directly, the opportunity exists to manipulate both the rate of growth and the disposition of the animal to store fat by the development and application of intensive management systems designed to maintain a more precise balance between nutrient requirements and availability. The goal of this management system would be to provide cattle and sheep with a steady but limited supply of quality forage so that animal growth is maintained without excessive fat deposition and with a minimum loss of soft tissue during transit and other stress periods.

C. Conference problem 1.

The ability to produce slaughter animals with a predetermined body composition is severely hampered by an inadequate understanding of factors which control the partitioning of nutrients to lean vs fat. Factors include diet, namely quantity and form of energy, environment, genetics and previous nutrition and management of the animal. Hormone levels and age may mediate normal utility of nutrient type and load and result in different partitioning of nutrients. In addition partitioning agents and exogenous hormones may alter partitioning. Some animals are put in the feedlot shortly after weaning, whereas others are grown on a stockering program, grazing perennial warm-season grasses or cool-season annual grasses prior to being finished in the feedlot. This results in a more mature animal with a larger frame to be finished. Most of the consequences of differences in preweaning nutrition are mitigated by a stockering phase, resulting in a more uniform group of cattle. Research is needed to compare the effect of different lengths of stockering phase as compared to a growing phase in a feedlot and on the resultant feeding techniques necessary to produce the desired body composition. The effect of stockering on the required degree of fat composition to achieve the desired organoleptic properties in beef cuts is also worthy of investigation. In addition the factors which determine the body composition of animals being finished on grass with grain supplement have not been adequately addressed.

D. Conference problem 4.

The fat content of meat is the limiting factor for its inclusion in a health diet. One simple solution to this problem is to trim the excess exterior fat from the carcass during fabrication. However, this practice increases the fabrication cost and decreases the yield of edible retail product per carcass. The end result is an increase in the cost of the trim retail product. Because the cost of the fat is included in the initial carcass cost, the packer and retailer are reluctant to discard it. Therefore, they disguise the trim in ground meat products such as

hamburger, sausages, bologna, etc. Since about 40% of the meat in the diet in the U.S. is composed of ground meat, trimming does not appear to be a feasible solution to reducing total dietary fat intake. Instead it is a temporary solution to the increasing consumer demand for leaner retail cuts of meat so that meat can still be a viable part of the daily diet without exceeding the levels established for fat intake.

Surveys have shown that the consumer is willing to pay more for a leaner product but how much more is not clearly known. A further question is whether it is more efficient to produce the desired product by fabrication or is it more efficient to decrease fat content before fabrication through biological means or management. Consistency of quality parameters such as palatability, juiciness, and tenderness is a major concern when the fat content is reduced by slaughtering the animal before it reaches choice grade. Are the palatability factors of a cut of meat trimmed to a certain exterior fat the same as for a cut at the same exterior fat achieved through nutrient partitioning agents, high forage diets with more moderate rates of growth than concentrates diets, slaughtering at lighter weights or different dietary energy densities at different times through the life cycle?

Fat composition is not as significant an issue unless there is an adverse effect on palatability. Fat composition is not easily altered in the ruminant due to saturation of dietary fats by the rumen fauna. Previous attempts to change fat composition has had adverse effects on carcass quality. Previous management of the young animal may affect the ability of the animal to deposit and mobilize fat. Therefore since beef animals spend over 75% of its life consuming forages there is a need to understand how the various animal genotypes and forage systems interact to impact the fat deposition mechanism.

MAJOR PROBLEM AREAS IN ANIMAL NUTRITION FOR
THE U.S. DAIRY FORAGE RESEARCH CENTER

Madison, Wisconsin

Goal: Increase use of forages by dairy animals.

The purpose of this is to increase the market for forage crops that could be produced on erosion prone lands currently used for cereal crops or the conservation reserve program.

Problem 1: Plant cell walls limit the consumption and digestion of forages. Reducing or alleviating this limitation to efficient forage utilization by high producing ruminants is hampered by lack of information concerning:

a. The physical/chemical relationships of complex carbohydrates in the cell wall matrix and their effects on cell wall utilization.

b. The role of lignin and phenolics on cell wall digestion and intake.

c. The rate limiting processes in ruminal turnover (digestion, passage and particle size reduction) of plant cell walls.

d. The effects of ruminal environments associated with high intakes and concentrate feeding on rumen fermentation of fiber.

e. Systems of ration formulation that maximize forage intake yet meet energy and nutrient requirements of highly productive ruminants.

f. Characteristics of the diet and animal which limit the rate and maximal extent of digestion of cell walls.

g. The relationships of cell wall composition and characteristics to the end-products of microbial fermentation and their effects on efficient energy utilization in ruminants.

h. The mechanisms by which high, moderate and low fiber diets limit net energy intake.

i. The effects of shifting the site of fiber digestion to the intestines during high intakes and rapid ruminal turnovers on forage energy and protein utilization.

j. The negative associative effects of feedstuffs and nutrients on cell wall digestion kinetics.

k. Practical systems for predicting the net energy value of feeds based on their chemical composition, the ingredient composition of the ration in which they are fed, and the physiological status of the animal consuming the ration.

l. The relationships between feed composition, animal intake and selectivity, and forage digestibility.

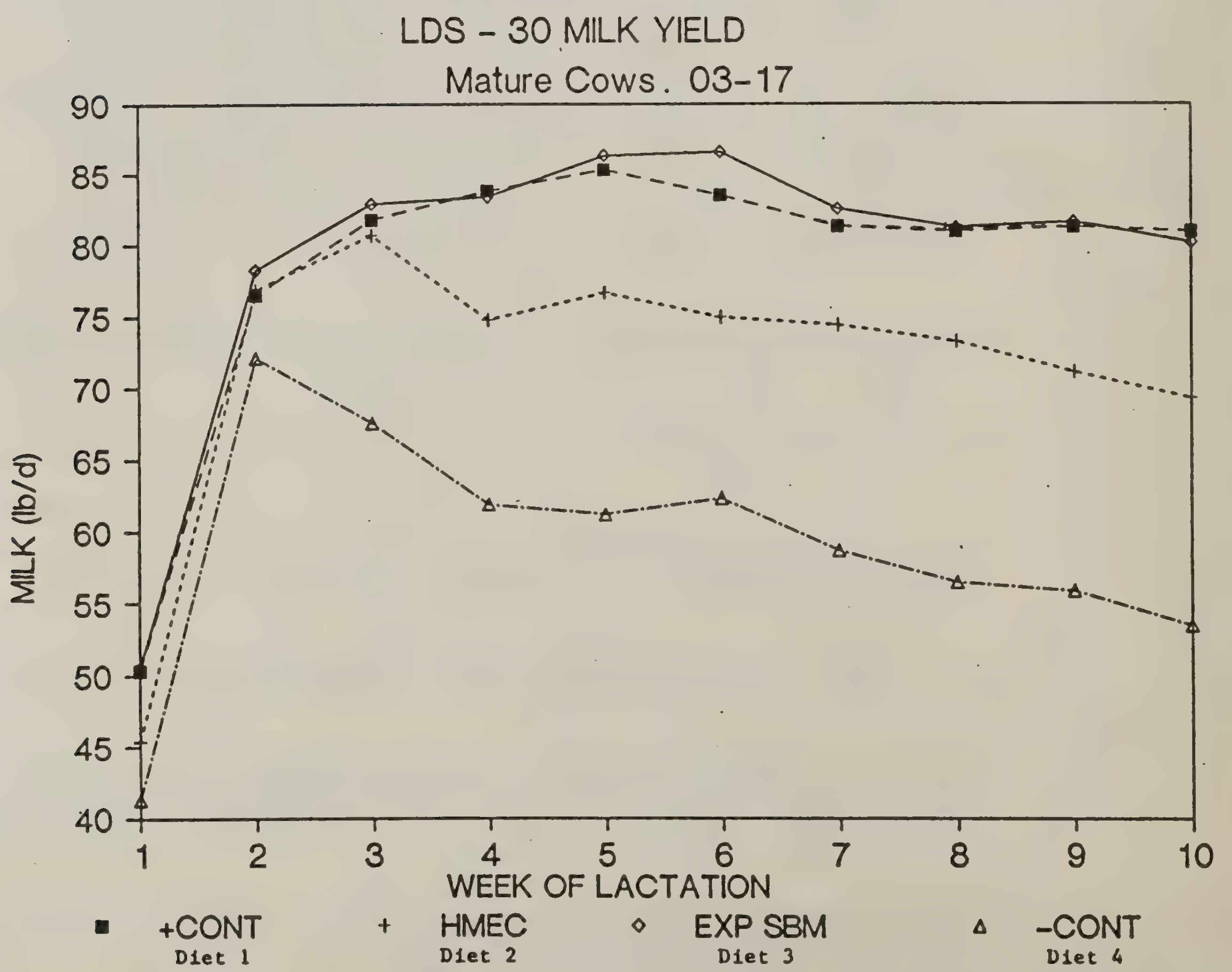
Problem 2: <u>Poor utilization of protein in high forage diets, especially high quality legume diets.</u>

Forage proteins are easily degraded by rumen microbes, and only 15-30% of the protein in forage escapes degradation in the foregut. With high quality legume forages, protein rather than energy may be limiting. The reason for including grain in dairy diets based on high quality legumes may be to improve protein status of the animal through increased microbial protein synthesis in the rumen.

The figure below illustrates the problem and shows milk production response in cows fed a conventional 50:50 (forage:grain) diet during the first two weeks of lactation and then, starting at the third week, followed by one of the four diets below:

Diet 1: Continuation of the 50:50 forage:grain diet fed during the first two weeks.
Diet 2: A diet containing 80:20 (forage:high moisture ear corn.
Diet 3: A diet containing 80:20 (forage:expeller soybean meal).
Diet 4: All forage diet, supplemented with a mineral and vitamin mix.

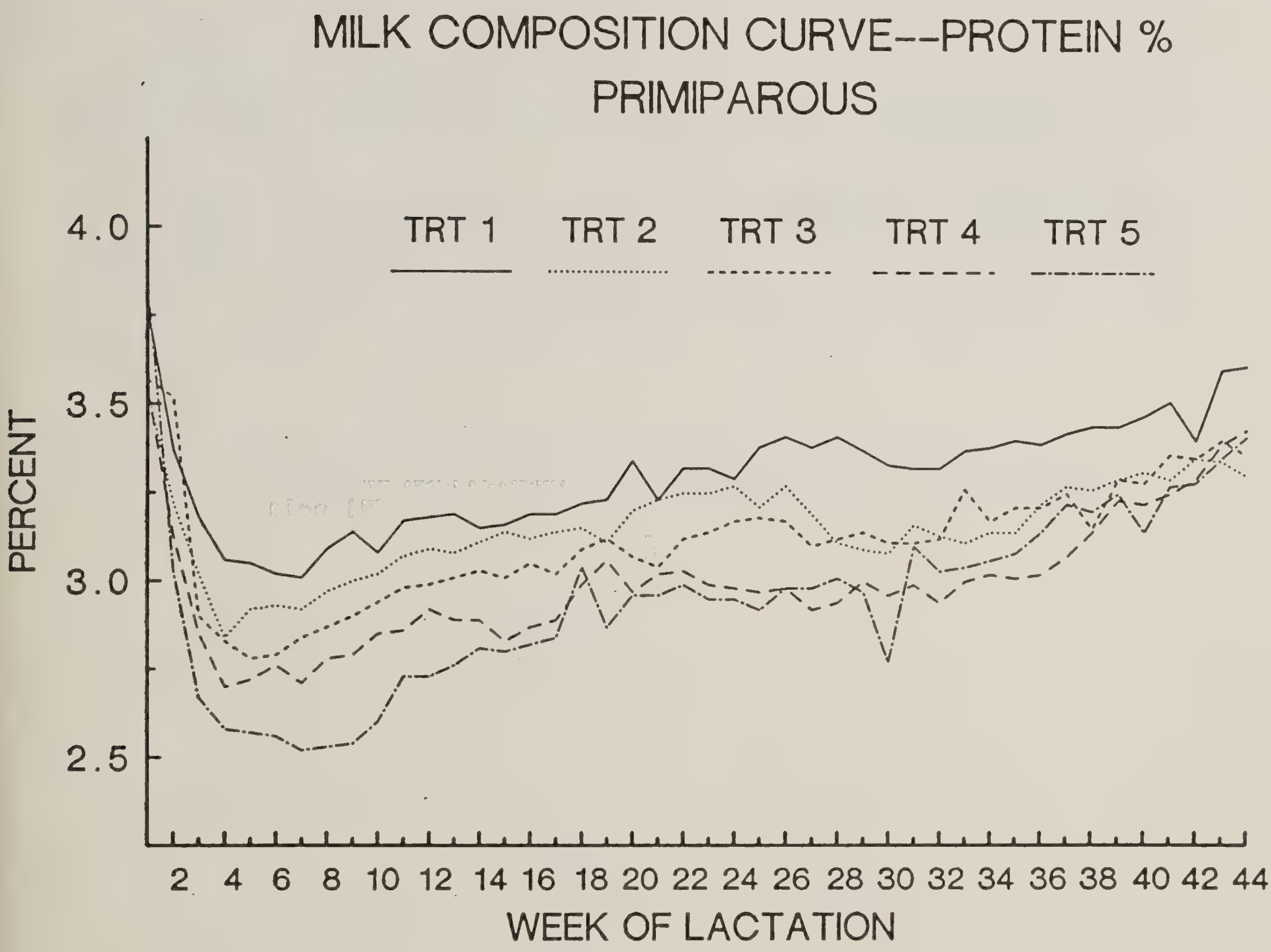
The forage is alfalfa silage containing about 23% crude protein and 38% NDF.



Milk production response to diets differing in protein and energy concentration.

The figure illustrates that Diet 3, though approximately isoenergetic with Diet 2, supports the same level of milk production as the conventional diet containing much more grain. Diet 3 supplies more protein to the intestine because of the higher 'by-pass' protein in expeller soybean meal.

In addition to the poor utilization of dietary protein when high forage diets are fed, the percent of milk protein is reduced when high forage diets are fed. This is illustrated in the figure below showing percent milk protein throughout the lactation when diets containing different proportions of forage are fed.



Key to Diets*

Weeks of Lactation	Treatment 1	2	3	4	5
	---------% Forage in Diet (DM Basis)---------				
1-12	38.2	48.2	58.2	68.2	98.2
13-26	48.2	58.2	68.2	88.2	98.2
27-44	68.2	78.2	88.2	98.2	98.2

*The balance of the diet was high moisture ear corn, soybean meal, mineral and vitamin mix. The diets contained about 19% crude protein in early lactation and about 16-17% in mid and late lactation. Diets containing more than 88% forage exceeded these protein levels.

The large reduction in milk protein content as forage content of the diet is increased presents a serious problem for increased forage utilization by the lactating dairy cow.

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March 23, 1988

SUBJECT: List of Research Areas for Nutrition Workshop

TO: Travis Littledike, NPS

FROM: T.S. Rumsey, Research Leader, RNL TSR

The following is a list of research areas that Scientists within Beltsville RNL judge are critical to future progress and(or) address important new areas of research in animal nutrition. For the most part, these itemized areas are fit under the designated problems as outlined for the workshop with the flexibility of broadening the scope of the problems to include metabolic costs as a component of nutrient partitioning and to broaden product output to include milk and eggs. We have tried to identify the research area in the first sentence of each itemized area and have included the related verbiage that each scientist judged important to support or clarify the research need.

We judged that two additional problems should be included: 1) Difficulty in predicting diet quality and nutrients available for absorption (I.) and 2) Need to understand nutritional/health relationships as they impact animal production (VI.).

I. PROBLEM: <u>Difficulty in predicting diet quality and nutrients available for absorption.</u>

IMPORTANT RESEARCHABLE AREAS

1) Feed composition at the chemical and physical structural levels needs intensive amounts of work. Better definitions and assays are needed for entities such as lignin and fiber. At present, the assays we use are too general in nature, with the constituents which comprise these factors varying from sample to sample.

   Information acquired will have direct use in the areas of understanding feed utilization by ruminants, plant breeding, forage evaluation and the further development of near infrared reflectance spectroscopy as an analytical tool.

2) Lack of predictable control of rumen function due to the gap between in vitro and in vivo information. Ability to use non-competitive and/or fibrous feedstuffs to which ruminants are predisposed to eat and digest is limiting. In other word's we can't use the "rumen" in ruminant to fullest advantage.

   Strong agronomy/ruminant nutrition interaction to provide robust, accurate predictors of productive performance (of animal or diet origin) that apply to the gamut of conventional or novel feeds. Innovative research that goes beyond particle size, ADF, NDF, current protein concepts and current microbial fermentation techniques. <u>Emphasis is needed on structural chemistry of feeds and dynamic, in vivo studies of fermentation kinetics, e.g., NMR of forages and isotopically labelled feeds.</u>

3) To quantitate energy and protein derived from intake and digestion of forages, including rates of particle size reduction, nutrient digestion, nutrient production and nutrient flow in the gut in relation to nutrient metabolism.

   It is important that we know the quantities of nutrients supplied to the animal from the forage consumed. Ruminants are unique animals because they digest cellulose, a structural carbohydrate in forages. Forages are noncompetitive feedstuffs with regard to nonruminant consumption. Ruminants consume forages as a large proportion of their dietary energy supply. Intake of forage contributes about 57% of the total feed units offered to each lactating dairy cow (Allen, 1981).

   Forage research should integrate measures of tissue metabolism of digestion end-products so that the energy status of the animal may be assessed.Digestion of forages is the single most important variable in determining the overall use of feeds since the feces represent the largest nutrient loss by the animal (Mertens, 1985). Ruminal

digestion of feedstuffs is a major factor contributing to nutrient supply available for absorption. Intake may account for 50-75% and metabolism of nutrients, 10-20% of the variation in performance among animals. In combination with blood glucose and carbon dioxide, the production of volatile fatty acids represent a major portion of the energy producing pathways of ruminants and therefore, may help explain differences in the efficiency of metabolizable energy use for tissue energy gain from forages.

New techniques are being developed to quantitate digesta flow and reduce variation in nutrient flow measurements. More research is needed to develop an automated sampling device, test digesta flow probes and to continue in designing a cannula which maintains patency for total diversion of flow over long periods of productive life of the animal. Radio-labeled forages are being used for estimates of particle size reduction in the rumen and for estimates of microbial dry matter production in the rumen.

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4) Identify genetic changes which are likely to enhance fiber digestion and bacterial synthesis in selected rumen anaerobic bacteria.

Biochemical information is needed as to rate limiting steps in fiber digestion and bacterial synthesis under varying conditions common to the rumen of farm animals. Incorporation of genetic material into select bacteria and evaluation of ability of the organism to be maintained in competition with a mixture of microorganisms common to the rumen needs investigation.

Currently, there is a shortage of scientists who have expertise in anaerobic microbiology, bacterial genetic and biochemistry techniques and interest in improving animal production via research in intestinal microbiology of farm animals.

5) Identify where metabolism by microorganisms leads to the production of end-products that are less valuable to host animal than original substrate, or where products produced are not as useful as others might be.

Specifically identify the bacteria that produce the poorly used product, such as D-lactic acid, and genetically change the bacteria to produce another product, such as L-lactic acid in this case. Or find a means which might prevent the

changing of a substrate by passing it unchanged from the rumen.
Many farm animals suffer from health related problems that result from the consumption of highly fermentable diets and D-lactic production. If the organisms that produce primarily D-lactic acid were to instead produce L-lactic acid some health benefit might result. Other examples of changes that might be helpful include prevention of saturation of unsaturated fatty acids or the degradation in the rumen of high quality protein to bacterial protein of lesser value. This could result in the production of products which might more closely match consumer preference than would otherwise be produced.

6) Further define the interaction between digesta and epimural bacteria as regards their effects upon absorption, recycling and enzyme activity toward compounds in the intestines of farm animals.

   In the rumen, for example, the role of the digesta and epimural bacteria toward providing the rumen with urease activity needs to be defined. This might provide a means for better control of the rate of dietary urea hydrolysis.

   The role of the flow of saliva and flux of urea across the rumen toward urease activity of digesta and epimural bacteria has not been defined. This information might provide a means whereby the urease activity of the rumen could better match the needs of the microbes for ammonia used for bacterial protein synthesis.

7) Determination of the real-time changes in feedstuff composition during digestion in animals with the use of NIRS and fiber optics technology.

II. PROBLEM: Difficulty in accurately producing slaughter animals with predetermined body composition.

IMPORTANT RESEARCHABLE AREAS

1) Identify the factors that are associated with variability in production responses by animals. We have focused to a great extent on the pluses associated with the high performance animals and have sought to push animals in this direction. In reality the majority of animals are not top performers. It might be better to identify those animals that are in the bottom 25% and begin to understand and eliminate the factors that are associated with the feed and management waste associated with that fraction.

2) Forage research for dairy cattle has neglected estimation of metabolism of digestion end-products. Simultaneous measurements of blood, tissue and hormonal metabolism should be conducted to integrate measurements of digestion of forages with an understanding of mode of metabolism of nutrients for production of meat, milk and wool. For example, intake of grass may reduce milk production in dairy cows, but increase daily milk fat yields compared with intake of legume. What specific factors limit the production of milk fat from legume-fed cows? What specific factors limit the production of milk from grass-fed cows? How could these limitations be reduced or altered? Certainly, digestion is the major factor causing differences; but after nutrient supply is established, how are absorbed nutrients used differently? Integrated research is required to answer these questions completely.

3) Define interactive mechanisms, endocrine and nutritional, that regulate growth and nutrient deposition in the ruminant.

   We know through research with exogenous treatment with specific hormones, genetic engineering and other treatments that inhibit or enhance a given endocrine factor, that specific hormonal substances regulate growth and tissue deposition. Individual nutrients or metabolites have also been shown to affect regulatory mechanisms. As we develop our base of knowledge on key endocrine and nutritional factors regulating nutrient utilization, it is important that our data base include the interactive role these factors play in growth regulation.

4) Tissue culture studies to compliment in vivo designs aimed at achieving increased net protein accretion.

5) Identify physiological deficiencies to be overcome by gene transfer.

III. PROBLEM: <u>Difficulty in accurately producing slaughter animals with predetermined body composition.</u>

IMPORTANT RESEARCHABLE AREAS

1) The largest single "cost" or loss of potential nutrition is during digestion and absorption

   Critical needs are to measure rate, extent and cost of nutrient absorption and to identify the gut's role in endogenous or exogenous regulation of metabolism. To apply that information to strategies to minimize cost of gut function.

2) Manipulate differentiation to generate a profile of cell types that are more protein accretion oriented. As animals develop and grow, there are inherent pathways of differentiation that determine the numbers and patterns of cell types that will ultimately give rise to tissues that will utilize nutrients for muscle accretion or fat synthesis. Manipulation of these tissues after their differentiation is complete (to achieve increases in the proportion of nutrients that are given to protein accretion) by implementation of hormonal, nutritional and even genetic techniques, is limited in scope. Several reasons for this exist. Once cells are differentiated they are committed to a specialized function. Severe attempts to compromise function of one cell type usually partially down regulates function of other cell types. Finally, homeostatic mechanisms are evoked that attempt to maintain a "normal" internal environment and a significant portion of the metabolic effort is directed toward countering a metabolic insult. Therefore, attempts to manipulate differentiation to generate a profile of cell types that are more protein accretion oriented might prove more effective than forcing tissues to perform in manners to which they are not intended.

   Because of the enormous amplification in cell numbers that occur (one billion fold between embryo and birth as contrasted to only several hundred fold following birth), the slightest effective change in the differentiation of cells either away from adiposites or toward muscle-type cells or their supportive juxtaposed cells can lead to a significant redistribution in the cell-type patterns that come to be. In addition the physical patterns of these cell types, that is the anatomical location, may be shiftable. Presently few data exist that address the ability of the embryo to be affected by selective growth factors that have impact on differentiation. The ultimate benefit to production would be the generation of animals that do not have the inherent propensity to fatten with aging. In addition, while genetic engineering may be of potential benefit, the present developments in farm animals have been without significant improvement in growth parameters. In fact most evident has been the development of signs of

inherent metabolic derangement. Embryo manipulation might overcome some of these drawbacks because the genetic material is not being altered and following a limited "push" in the desired direction, the subsequent development would be consistent with normal fetal maternal controls. Even if this was initially dependant on short term exutero culture and return to the uterus, it allows the generation of a data base that would address the feasibility. A possible additional impact on production would be a reduced manpower need based on less intensive management practices by elimination of implanting and adherence to Agency regulated withdrawal times etc.

The approach to this research is dependant on two thrusts. The first is the identification of the normal cellular responses to nutritional and normal physiological stimulations that are associated with nutrient partitioning. This involves the generation of hormonal profiles, receptor responses and cell responses as animals age. In addition much of the "pure" effects might be best studied in vitro as the growth conditions can be finely controlled. Secondly, information on the responsiveness of the embryo to manipulation needs to be explored. Again this would require both in vivo and in vitro efforts.

3) Isolate the dietary cause and mechanism of decreased energetic efficiency of ME for growth from orchardgrass relative to alfalfa.

4) Determine if early growth rate of heifers influences subsequent lactation performance (start ≤ 100 kg up to puberty, 275 kg in Holsteins).

5) Understanding of splanchnic tissue intermediary metabolism and its regulation is lacking. The ruminant gut and liver have a high rate of metabolic activity relative to other body tissues (producing 40 to 50 % of total body heat). This metabolic activity determines the quantity and structure of absorbed dietary nutrients eventually available for utilization by other body tissues. A clearer picture of carbon and nitrogen flow from the gut lumen to the arterial supply for productive tissues (muscle, mammary gland, uterus) should enhance our ability to repartition nutrient flow towards greater protein production.

The further development and adoption of stable isotope and NMR techniques for tracking nutrient metabolism in vivo could greatly advance our knowledge of nutrient partitioning in ruminants. While data describing net metabolism of gut and liver are becoming available, actual rates of nutrient uptake and release and the interchange of carbon, nitrogen, hydrogen and oxygen within gut and liver tissues are still missing. The use of isotopes for tracking the metabolism of specific substrates is a proven mechanism for obtaining actual rates of uptake, release and molecular atom exchange

Improving Efficiency of Protein Production in Lambs

Background Information

The number one problem in the sheep industry is that approximately 60% of the lambs are too fat at slaughter. The concern of the modern consumer over excessive fat will preclude future expansion in lamb consumption if this problem is not corrected. The fact that lamb has been in chronic short supply for several years, and that lamb is such an insignificant portion of the total meat supply, has not caused public concern over excessive fat in lamb as it has in beef and pork. Nevertheless, the problem is real, and will eventually result in major negative consequences to lamb consumption.

I would argue that 70 percent or more of the lambs produced in the U.S. are capable of being highly desirable in terms of low fat content and desirable organoleptic traits when they are sold by the primary producer. These lambs, in general, are 4 to 6 months of age, weight 90-120 lbs., have less than 0.2 inch backfat, and have consumed little or no concentrate feed at this time. The only major exception to this would be lambs from the more arid regions (desert southwest, parts of Wyoming, etc.) from which a 70 lb. feeder lamb may be the upper limits of the nutrient resources to the production system.

The problem, or blame, is with our traditional slaughter and processing industry that has not been economically motivated to change due to the fact that, for a major portion of the year, lamb is in short supply and is practically "rationed" out of the slaughter plant to wholesalers and other buyers. Most of the lamb is still sold as hanging carcasses. The slaughter plant operator, therefore, is concerned about "yield or dressing percent" (i.e. pounds carcass vs. pounds live lamb purchased). The way to obtain higher yields is to get the lambs fatter, and this fat is not the packer's problem since he is able to pass it on to the next buyer in the system. As a result, the 110 to 115 lb. highly desirable lambs sold by the producer in the intermountain states are not being slaughtered, but are going into a feedlot where $.35 to $.40 per pound gains are possible and being "fattened" to 130 to 140 lbs. to meet packer demands for "higher yielding" lambs.

The greatest hope for a resolution to this problem is with two current trends being seriously considered in the lamb slaughter industry: (1) further processing to retail product at the slaughter plant, and (2) a growing realization that the concern over excessive fat is real and must be dealt with. Further processing at the slaughter plant to retail shelf-ready product has tremendous potential in the lamb industry. Lamb plants that slaughter over 10,000 lambs per week can make "experts" out of unskilled labor, while the supermarket butcher (at twice the hourly wage) will never become an expert lamb processor when lamb is less than 1% of his total meat business.

Further processing allows the processor to merchandise cuts to specific high value markets and thus add value to the product. The realization that the concern over fat is for real comes from the fact that approximately 75 percent of the lamb slaughter is by companies that also slaughter beef cattle and swine, where the pressure on excessive fat is the greatest.

With a few minor exceptions, the lamb slaughter companies are seriously evaluating, and/or developing, further processing systems. These tend to include "brand-name" products for their superior cuts. When the slaughter plant becomes the site at which excess fat must be removed and discarded, the plant suddenly becomes very concerned about excessive fat. For the first time in history, at a recent meeting, a major lamb packer suggested that mandatory yield grading of lambs should be considered. When this happens, the mechanisms will be in place to put a price incentive on the production of leaner lambs.

The point of this discussion is that we have the genetic and management resources in place to produce higher protein, lower fat lambs. Producers are utilizing these genetic resources and production systems at an increasing level. It now appears that the "post-harvest utilization" of the product we produce is finally joining the 20th century.

Research Approaches

1. The highest priority relates to problem 3 in our agenda - a rapid, simple, economical method of determining body composition of the live animal. To be used by the industry, it must be fairly simple and economical, and should be compatible with the high speed electronic weighing equipment that is available. For research purposes, accuracy is the primary need. This does not simply relate to feeding trials and research on slaughter animals, but is desperately needed for more reliable research data in nutrition and other studies on the reproducing male and female.

2. Producing lambs to a predetermined weight and composition. The immediate solution to the problem of excessive fat in lambs is to slaughter at lighter weights, or do not feed high concentrate feeds for as long a period as is currently practiced. The trend, due to overall economic efficiency and changes in consumption patterns, is toward larger lambs and thus larger cuts. We, therefore, need to develop nutritional regimes that will permit heavier slaughter weights at the desired body composition. The discussions on nutrient partitioning and controlling fat synthesis and degradation are pertinent to this problem.

3. Over one-half of the slaughter lambs could be much leaner at slaughter, and more efficient in feed conversion, by simply not castrating the males. Intact male lambs slaughtered at 150-180 days of age are significantly leaner and require less feed per unit of gain than castrates. However, as ram lambs approach puberty the pelt becomes more difficult to remove from the carcass and causes severe problems with mechanical hide pullers. Can this problem be overcome? Can we overcome management problems with ram lambs mixed in with ewe lambs and their dams and not sold before they reach puberty? What about delayed castration (i.e. castration at 45, 60, 75 lb., etc.)?

4. Although the logic and purpose of our agenda for this meeting is recognized, we are overlooking the primary consumer of nutrients in animal production systems. In beef cattle and sheep, between 50 and 70% of the nutrients required to produce a pound of carcass are consumed by the reproducing female. Reproductive efficiency, or pounds of lamb weaned per ewe in the flock, is the primary determinant of profitability in range sheep production systems. Both experience and research results tend to confirm that there are antagonisms between reproductive efficiency and extremes in lean meat production.

5. With statement number 4 in mind, it would appear that production efficiency of the total system is the primary determinant of genetic resources. The next factor is to determine optimum slaughter weights for the genetic resources adapted to the particular production systems. The only alternatives are possible solutions through research to problems 2 and 4 in our agenda.

III. ARS NUTRITION PROGRAM CATEGORIZED BY SUBJECT

SUBJECT	# CRIS PROJECTS	FUNDING 4/6/87 (Net to Location)
Composition and Bioavailability	7	891,646
Forage Utilization	15	1,568,901
Harvesting, etc., Forage	1	109,605
Silage	3	319,036
Growth	9	1,778,226
Adipose Tissue	2	291,056
Protein	3	822,154
Rumen Microbiology	8	1,169,619
Fiber	6	663,279
Nutrient Absorption	4	540,552
Regulation of Metabolism	6	553,549
Energy Metabolism	3	1,043,540
Hormone Effects	7	1,614,280
Feed Efficiency Techniques	1	18,171
Milk Synthesis	1	357,385
Meat Quality and Grading	2	184,185
Aquaculture	5	1,123,650
Stress	8	1,014,270
Systems Modeling	7	1,206,891
		==========
GRAND TOTAL		$15,269,995

IV. CLASSIFICATION OF ARS NUTRITION PROGRAM BY STEPS IN UTILIZATION OF NUTRIENT

PLANT

- Forage management (Great Plains) - Adams - 77,718
- Growth and nutrient characterization as judged by animal - Burns - 0$

HARVEST & PROCESS

- Enhancing forage value during mowing thru utilization - Koegel - 109,605
- Modeling of ensiled forage quality - Muck - 105,000
- Prevent proteolysis in hay silage by varying alkaline minerals - Shockey - 109,036

ANIMAL FOOD

- Forage analysis - NIR and stress on early performance - Lamb - 152,335 and 52,335
- Enhancing role of forage in dairy cow - Satter - 223,042
- Characterize and modify properties limiting utilization - Abrams - 103,778 and 69,186

INTAKE

- Feed restriction to improve feed efficiency in chickens and turkeys - McMurphy - 18,171 and 102,500

DIGESTION

- Bioavailability of nutrients from feedstuffs for ruminants - Gallavan (2) - 175,459; 75,197
- Phenolics effect to limit fiber digestion in rumen of dairy cattle - Jung - 115,049
- Chemical composition especially lignins and carbohydrates in determining feed digestability - Reaves - (260,442)
- Structure, composition and microbial limitations to plant nutritive quality - Akin - 89,786
- High vs. low quality diet in goat efficiency - Hart - 20,000 specific coop agreement
- Availability of minerals for dairy - Martz - 123,378
- Grass vs. legume - Glenn - 296,545

DIGESTION (Continued)

- Cool vs. warm season grasses - Jung - 13,500
- Alfalfa vs. alfalfa-grass combination - Baxter - 70,584
- Optimizing utilization of forage for dairy cow - Satter - 45,000
- Effect of diet on composition and efficiency of growth and subsequent milk production - Waldo - 176,541
- Genetic engineering of rumen microorganisms - Hespell - 256,538
- Studies of lignocellulose-degrading rumen forage - Akin - 0$ SA
- Effect of rumen microbial dynamics on nutrient conversion - Slyter - 181,008
- Identify major microbiological interactions that maximize forage utilization by dairy cattle - Satter - 145,600 and 65,400
- Factors affecting bioenergetics of rumen bacterial growth - Russell - 117,173
- Characterize and use fiber digestion kinetics to maximize the use of forages in dairy rations - Mertens - 163,988 and 70,280
- Rumen digestion kinetics of intrinsically labeled neutral detergent fiber - Smith - 77,039
- Influence of diet composition and intestinal environment on the utilization of fiber in swine - Calvert - 197,598
- Relation of gastrointestinal heat production to efficiency use - Reynolds - 151,383

ABSORPTION

- Bacterial fermentation and end-product absorption - Varel - 114,872
- Internation among fiber structure, bacterial fermentation and end-product absorption - Varel - 28,718
- Characterize fiber and warm season grasses in relation to their utilization by ruminants - Jung - 77,335
- Control by the gut of uptaxe and subsequent use of nutrients by beef and dairy cattle - Huntington - 164,371 and 134,485
- Gastrointestinal epithelium and pancreas functions: effects on nutrient absorption - Pekas - 48,339 and 193,357

METABOLISM

- Forage protein utilization by high producing dairy cows - Broderick - 208,575
- Interorgan metabolism during growth - Eisemann - 139,000
- Selecting pigs for faster growth of lean tissue under low and high dietary protein intake - Bereskin - 307,500
- Bioregulation of fetal, neonatal growth of pig and adipose and skeletal muscle tissue - Kraeling - 368,262
- Nutrient partitioning during compensatory growth in poultry - McMurtry - 163,957
- Altering growth and fat deposition of broilers through the amino acid and energy interrelationships of the diet - Cartwright - 15,000 SA

METABOLISM (Continued)

- Neural factors controlling avian growth and development – Rosebrough – 164,186
- Adipose tissue differentiation in vertebrate animals – Hausman – 10,200 SA
- Control of fat accretion by regulation of adipose tissue metabolism – Mersmann – 201,237
- Porcine adipocyte antibody to decrease fat – Mersmann – 15,000 SA
- Biochemical mechanism of lipid and protein deposition in poultry – Foglia – 89,819
- Prevent protein catabolism through precise determination of protein requirements of ruminants – Lynch – 320,091
- Increase lean meat production rate and quality in high forage diets – Bond – 197,582
- Protein synthetic and degradation rates in swine selected for dietary protein utilization – Mitchell – 304,481
- Determine metabolism and utilization of dietary and gut microbial products in swine – Varel – 263,310
- Regulation of metabolism in hind limbs and liver of ruminants – Eisemann – 38,140 and 152,559
- Physiologic sectors affecting avian metabolic efficiency – May – 85,813 and 85,813
- Genetic physiological mechanisms associated with nutrient utilization in poultry – Marks – 34,214
- Nutritional and physiological factors affecting poultry productivity and product quality – Cartwright – 157,010
- Influence of nutrient site of digestion on energy metabolism of growing beef cattle – Reynolds – 284,325
- Nutritional regulation of partition of dietary energy by dairy cattle – Moe & Tyrrell – 607,832
- Somatotropic hormonal regulation of rate and pattern of growth in red meat animals – Klindt – 299,581
- Estrogen, thyroid and pituitary hormone control of tissue protein deposition in beef cattle – Rumsey – 545,237
- Endocrine regulation of adrenal, gastrointestinal and uterus-ovarian function in ruminants – Zavy – 104,400
- Effect of autocrine and paracrine agents on muscle growth – Schollmeyer – 130,580
- Study of growth hormone and glucocorticoid interactions in rats and pigs – Steele – 7,200 and 16,800 (Etherton)
- Fetal, maternal and preweaning effects of beta-agonists treatment of swine – Steele – 279,715
- Protooncogene expression by trenbalone acetate and growth hormone – Campion – 11,100 SA?
- Endocrine regulation of fat/lean ration in poultry and swine – Rosebrough – 163,663
- Growth hormones, somatomedin and thyroid regulation of growth in turkeys – Opel – 161,104
- Biochemical mechanism regulating protein and lipid synthesis in bovine mammary gland – Farrell – 357,385
- Measuring stress in range beef cattle in Northern Great Plains – Currie – $0

METABOLISM (Continued)

- Environmental temperature stress and poultry nutrition - Denton - 86,659 and 86,659
- Environmental stress and poultry health - Denton - 221,625
- Characterize meat animal response to environmental stressors - Hahn - 242,139 and 80,713
- Management effects on stress and dairy performance - Lamb
- Physiologic responses of swine to actual and simulated changes in production environment - Becker - 184,298
- Milk, by which environmental stress inhibits milk removal and synthesis - Lefcourt - 59,842
- Cellular milk of response and adaptation of the adrenal during acute and chronic stressors - Klemcke - 100,000
- Relation of mature size and milk yield to life cycle production efficiency of cows - Jenkins - 202,603

ANIMAL PRODUCT

- Effect of breed, diet and sex on growth and quality - Crouse - 219,031
- Correlate yield and quality with rearing, processing and nutritional factors - Merkley - 227,394

PROCESS

- Early postmortem biological events regulating the tenderness of red meat - Koohmaraie (Crouse) 40,004
- Meat grading expert system - Chen - 144,181

HUMAN FOOD

- Human nutrition and postharvest program - 30+ million

SYSTEMS

- Grazing systems for sheep (several projects)

MISCELLANEOUS

- Aquaculture (five projects)